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WASTE FILLING OF STOPES

BY

CHARLES F. JACKSON

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WASTE FILLING OF STOPES[1]

By Charles F. Jackson[2]

INTRODUCTION

Waste filling has been employed for many years for supporting the walls of stopes and preventing failure and subsidence of the surrounding and overlying rock formations, and its effectiveness for this purpose has long been recognized. It is used for permanent support in ground where timbering (including square-setting) is inadequate for more than temporarily supporting the walls of the excavations.

It should be noted, however, that effective as a good, solid fill may be in resisting heavy side pressure and direct weight, its usefulness for supporting large areas of back and preventing breaking and movement of the overlying rocks is limited. Even the strongest and most uniform rocks will break if the unsupported span becomes too great; and since filling cannot be packed tightly against a horizontal back there is always a possibility of the back breaking and consequent subsidence if the maximum self-supporting span is exceeded. Planes of separation, such as bedding and fault planes, slips, and joints, are common in all rock masses; these may occur above the stoping area where their presence cannot be ascertained by observation. If too much reliance is placed upon filling for the support of a large horizontal area of back (as contrasted to support of vertical or steeply inclined walls) large masses of rock may break along a plane of weakness, compress the fill, and leave an open space into which caving of the overlying rocks may continue until the space is filled.

In this paper the term "waste filling" includes any filling material other than ore - waste mine rock, rock from surface quarries or opencuts, sand and gravel, mill sands, or slags from smelting operations.

PURPOSES OF WASTE FILLING

Waste filling of stopes is employed principally to support the walls of the excavations as an essential part of the mining operations, or as a convenient means of disposing of mine waste produced in the course of driving development openings in rock or of waste broken with the ore in the stopes and there sorted to obtain a better shipping or milling grade of ore.

When employed for support filling may be introduced (1) at frequent and regular intervals during stoping of the ore as one of a cycle of operations in cut-and-fill stoping or square-set stoping, (2) to fill completed and emptied stopes as a means of permanent support, or (3) to fill completed and emptied stopes preparatory to mining adjacent blocks of unmined ore, such as pillars between mined-out stopes, crown or floor pillars, or ore left in the walls of original stopes.

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1 The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U.S. Bureau of Mines Information Circular 6816."

2 Principal mining engineer, U.S. Bureau of Mines.

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In resuing, a form of cut-and-fill stoping sometimes employed in narrow veins of less than stoping width where ore and waste are broken separately and the waste is broken to make working room, the waste is left as filling in the stope to form a working floor for the miners and may or may not be required for support of the walls.

Filling has been used in old abandoned stope areas for the dual purpose of providing support to the surrounding and overlying rock and a working floor for systematically cleaning the walls of the stopes of remaining ore, following and mining stringers of ore in the walls, and prospecting the walls for possible blind orebodies which may have been missed in early mining and which have not been disclosed by development on the levels.

Mill sands have been used, as at Franklin, N. J., to fill the space above top-slice caves in pillar mining between filled stopes and to provide a cushion above the top slices to absorb the shock of any masses of capping that might break loose.

Filled top slices were employed for mining partly worked-out sections and heavy ground at the Charcas unit of the Cia Minera Asarca, S.A.[3] Filling has also been used for extinguishing mine fires and for sealing off fire areas.

FILLING MATERIALS

As previously stated, development rock, waste sorted in the stopes, rock from surface quarries, sand and gravel, mill tailings, or smelter slags may be used for filling stopes.

Sometimes enough waste is produced from current development work to provide all the filling necessary. In other instances, as in resuing or stripping, enough rock is broken in the stopes to supply the required amount of filling. Again, development waste and waste sorted in the stopes may together be adequate. Frequently, however, it becomes necessary to resort to other sources of filling material to obtain either the quantity required or the kind of filling desired.

Where development work and sorting do not supply enough waste raises or short crosscuts are sometimes driven into the hanging wall, or waste stopes are developed in barren sections of the mine where they will not endanger the levels or the ore stopes and where waste can be economically obtained by caving or other cheap methods. At some mines satisfactory material can be obtained from surface mills or gloryholes above the mine workings where it can be cheaply broken and transferred through a system of raises to the stoping sections of the mine. Again, nearby sand and gravel pits may provide the cheapest and best filling material, or mill tailings may be available in quantity and of a nature satisfactory for filling purposes.

Local conditions will determine in each instance the cheapest and most desirable filling material.

Where development and sorted waste provide enough filling other material is not usually considered, since the waste is broken anyway and usually is satisfactory.

With respect to low compressibility and ease of handling and placing, clean sand or coarse mill sand is perhaps the best material for filling. It usually compresses not more than 5 percent and if clean permits water to drain through it quickly. If it is very fine, however, there may be some difficulty in confining it within the desired limits; if it is used to fill stopes between pillars to be mined later either lagging must be used to hold it back, some ore must be left against it when the pillars are mined, or considerable care must be exercised in mining alongside it to prevent contamination of the ore. Finely granulated slag acts in much the same way. A mixture of clean sand and gravel has similar characteristics; but if the gravel is very coarse, some of the methods used for transporting, handling, and placing sand often are not suitable or if so the cost is considerably higher.

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3 Willey, Howard, Top-Slicing with Filling of Slices, as Used at the Charcas Unit of the Cia Minera Asarca, S.A.; Trans. Am. Inst. Min. and Met. Eng., Gen. vol., 1931, pp. 51-65.

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A mixture of sand and clay makes a good filling material for certain purposes and under certain conditions but is objectionable in other instances. In Russia[4] it has been found that a semiwet filling of clay and granulated quartzite in the ratio of 3 to 1 could be placed in layers 15 inches thick and that pillars between stopes so filled could be later taken out clean by cut-and-fill stoping without the use of gob lagging, the fill standing solidly while the ore is taken out. Shrinkage was as much as 50 percent by volume with this type of filling, but by placing it in layers and allowing each layer to settle before the next one was placed, little shrinkage took place in the whole mass later. Tests showed that dry filling shrinks to some extent; pure, dry clay shrank 30 percent, and clay with 25 percent quartzite shrank 15 percent.

Clay may be objectionable in filling if it renders the fill impervious to the passage of water. At the Hollinger mine in Ontario where sand filling is obtained from a pit some distance from the mine percolation tests are made on samples of the sand to make sure that no sand that will not drain quickly is being used for filling. Here a large amount of drilling water is used, and if an impervious filling mixture were employed the stopes might become reservoirs for large volumes of water which, owing to a slight movement of the ground or other causes, might suddenly be released causing the fill and stopes to collapse suddenly.

Sand containing some clay and some kinds of mine or quarry rock containing a small amount of moisture will settle and consolidate under their own weight or because of work over successive layers to such an extent that in a few months they will stand up alongside excavations 6 to 8 feet or more in height without breaking or moving. The advantage of filling of this nature is obvious when used in stopes surrounding pillars of ore to be mined later.

When coarse waste rock is used for filling, considerable shrinkage of the fill eventually will occur because of the large percentage of voids between the pieces. This type of filling may shrink for some time because readjustments of the aggregate take place rather slowly. Eaton[5] states that coarse waste may compress 10 to 25 percent before the fill develops its full strength. At the Tintic Standard mine filling in the stopes will settle as much as 7 feet between levels 120 feet apart before it comes to rest.[6] Shrinkage of the gob in fills can be reduced if wet material is available or if the fill is sprinkled as placed to reduce the voids.

To reduce the voids and facilitate handling and placing, waste is sometimes crushed to give a finer product. Thus, at the Magma mine,[7] where 50 percent of the waste for filling comes from a surface gloryhole the rock is first passed through a grizzly having 16-inch square openings and is then reduced in an 8- by 30-inch jaw crusher.

Coarse waste is objectionable for filling in cut-and-fill stoping since it increases the difficulty of laying an even floor before the next ore cut is taken. At Cananea[8] the coarser waste from the Colorada surface gloryhole is used for the body of each layer of fill and finer waste from the Kirk gloryhole, for the top foot or two.

In Europe the practice of building up dry pack walls of coarse waste around the stope and filling the space inside with fine waste has long prevailed but has not been used generally in this country. At the Copper Range mine, Painesdale, Mich., it was for many years the

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4 Ayvazoglou, W., The Method of Underground Mining of Iron Ore in the District of Krivoy Rog (translated from the original Russian of A. K. Bouldovsky): Inf. Circ. 6254, Bureau of Mines, 1930, 49 pp.

5 Eaton, Lucien, Sand Filling Through Pipes and Boreholes: Trans. Am. Inst. Min. and Met. Eng., vol. 102, 1932, pp. 33-42.

6 Wade, James W., Mining Methods and Costs at Tintic Standard Mine, Tintic District, Utah: Inf. Circ. 6360, Bureau of Mines, 1930, p. 11.

7 Snow, Fred, Mining Methods and Costs at the Magma Mine, Superior, Ariz.: Inf. Circ. 6168, Bureau of Mines, 1929, p. 22.

8 Catron, William, Mining Methods, Practices, and Costs of the Cananea Consolidated Copper Co., Sonora, Mexico: Inf. Circ. 6247, Bureau of Mines, 1930, 41 pp.

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practice to dry-wall the sides of the haulage levels and fill in behind with finer waste.[9] The circular ore passes or "mills" were formed by building dry walls of coarse waste; fine waste or sand filling was run in around them as the cut-and-fill stopes were carried upward (fig. 1).

Although wet waste makes a good filling in that it reduces voids and consolidates quickly it is often difficult to handle and spread. At the Pilares mine water accumulated in surface gloryhole funnels during the rainy season, thoroughly wetting the fill, which became so sticky that it was difficult to load and unload it in cars and to spread in the stopes.[10]

At the United Verde mine rock from open-pit stripping operations in the shovel pit and waste from underground development work is used for filling.[11] It consists mainly of diorite and porphyry, some of which is fresh and coarse, with enough fines to fill the voids. Only waste comparatively free from sulphides is used on account of the fire hazard in this mine. No effort is made to tamp the waste; the action of the water from the drills and the force of the falling ore from blasting cause it to settle about 8 inches for each 7-foot layer of fill. Subsequent settling in old stopes is very slight. The resulting compact fill offers little difficulty in later mining of level and vertical pillars.

Mill tailings have not been used extensively for stope filling in this country. At the Champion mine, Painesdale, Mich.,[12] mill tailings or stamp sand was at one time employed for filling stopes where waste from development and sorting was insufficient to supply the requirements.

At Franklin, N.J., rejected rock from the picking table and tailings from the mill were mixed with quarry rock and mine waste for filling emptied shrinkage stopes.[13] Later, filling in some of the lower stopes consisted mainly of mill tailings, and at present pillars are being top-sliced between sand-filled stopes.

At Matahambre, Cuba, classified mill tailings constitute a large part of the filling in cut-and-fill stopes.[14] The mill tailings, consisting largely of quartzite and shale, are pumped to a bowl classifier. On the average, 48 percent of the contained solids is taken out as sand and is discharged into the mine fill pipe. The average screen analysis of the classifier discharge was as follows:

Size	Direct percent	Cumulative percent
Plus 48-mesh	40	40
Plus 65-mesh	20	60
Plus 100-mesh	22.5	82.5
Plus 200-mesh	9.5	92.0
Minus 200-mesh	8.0	100.0

9 Schacht, W. H., Mining Methods of the Copper Range Company: Trans. Am. Inst. Min. and Met. Eng., vol. 72, 1925, pp. 346-370.

10 Leland, Everard, Mining Methods and Costs at the Pilares Mine, Pilares de Nacozari, Sonora, Mexico: Inf. Circ. 6307, Bureau of Mines, 1930, p. 26.

11 Quayle, T. W., Mining Methods and Practices at the United Verde Copper Mine, Jerome, Ariz.: Inf. Circ. 6440, Bureau of Mines, 1931, p. 16.

12 Schacht, W. H., Mining Methods of the Copper Range Co.: Trans. Am. Inst. Min. and Met. Eng., vol. 72, 1925, p. 363.

13 Haight, C. M., and Tillson, B. F., Zinc Mining at Franklin, N.J.: Trans. Am. Inst. Min. and Met. Eng., vol. 57, 1918, pp. 793-794.

14 Reichert, George L., Mining Methods at Mines de Matahambre, Matahambre, Pinar del Rio, Cuba: Inf. Circ. 6145, Bureau of Mines, 1929, 18 pp.; Filling Stopes with Mill Tailing: Eng. and Min. Jour., vol. 127, 1929, pp. 348-352.

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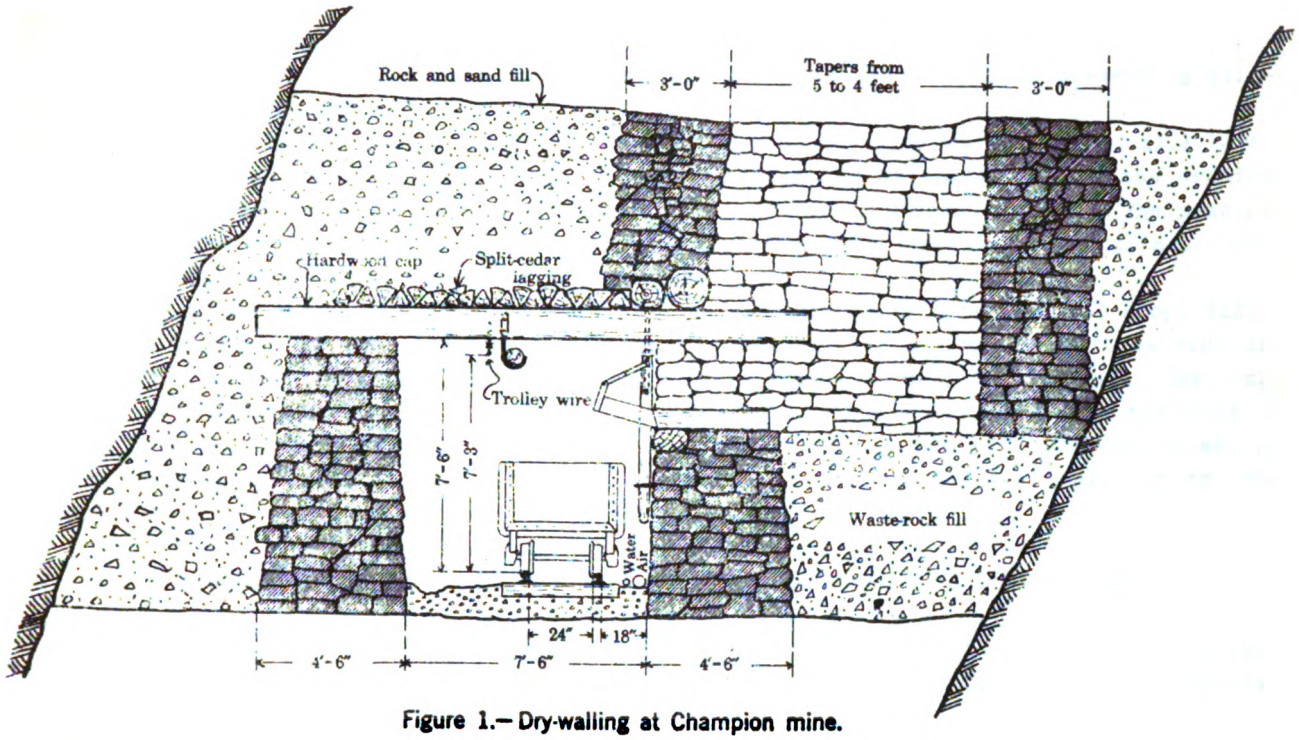

Figure 1.— Dry-walling at Champion mine.

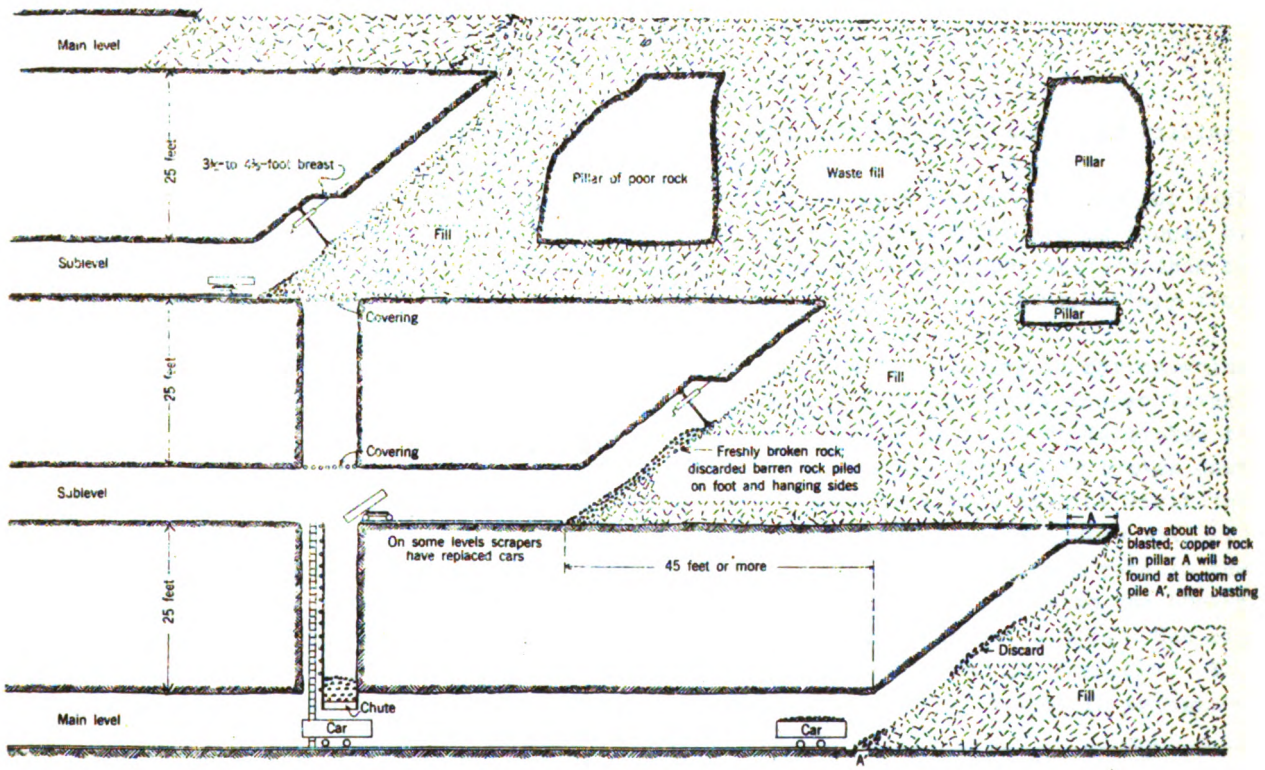

Figure 2.— New stoping method–sublevel, inclined cut-and-fill, Champion mine.

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The classifier overflow or slime product is run to waste.

The sand filling forms a hard, even floor in the stopes and assists in preventing dilution of the ore with waste.

Eaton[15] has discussed sand filling through pipes and boreholes and the use of mill tailings as fill in mines of the East Rand. The sand consists of tailings from the cyanide tanks; it is almost pure quartz, and the bulk of it is over 100-mesh in size. The cyanide remaining in the sand would be dangerous underground and must be removed or neutralized; usually it is neutralized with potassium permanganate.

So far as the author is aware, smelter slag is not used in this country for stope filling. Some time ago it was tentatively planned to use slag filling at the Noranda mine in Quebec. The smelter is close to the mine, and a large amount of slag is produced. The slag had been tested by casting it into blocks so shaped that they would interlock and form a solid, tight fill when placed in the stopes. More recently it has been decided to use a mixture of slag and mill tailings, in the proportion of about 20 percent tailings and 80 percent slag.

PROCUREMENT, STORAGE, TRANSPORTATION, AND HANDLING OF FILLING MATERIAL

By far the greater number of mines where stopes are filled with waste use rock for filling; even where sand and gravel or mill tailings are employed some mine waste usually is also used.

Rock Filling

Waste Procured in Stopes

Where much waste is sorted from the ore in the stopes it is the first source of filling, although it may be augmented by waste from other sources.

At the Cold Springs mine in Colorado 6.51 tons of run-of-mine ore are broken for each ton of sorted ore sent to the mill.[16] The vein is narrow, and much of the ore is stoped by stripping or resuing. Obviously more waste is obtained by stripping and hand-sorting than is required to fill the stopes, and excess waste is shoveled into the chutes separately from the ore and is transported to the surface.

At Questa, N. Mex.,[17] molybdenite ore is mined by cut-and-fill stoping in narrow veins up to 4 feet wide, but on the average the vein material is only 12 to 18 inches thick. Where the vein is wide enough to give working room and the walls do not have to be broken to fill the stope (that is, where enough fill can be obtained by sorting) the ore is broken down and the walls left untouched. If, as often happens, the ore is less than stoping width the practice is to break the foot wall away from the ore, sort out any ore that may come with it, and then take down the ore exposed on the hanging wall. Some sorting is always done in the stopes. If the ore can be broken clean, the coarse waste is picked out; otherwise the broken rock is shoveled onto an inclined screen of 2-, 1-, or, rarely, 1/2-inch wire mesh. The aim is to pass most of the ore through the screen and exclude as much waste as possible. The oversize is picked by hand. The amount of waste sorted varies greatly, but it is estimated

15 Eaton, Lucien, Sand Filling Through Pipes and Boreholes: Trans. Am. Inst. Min. and Met. Eng., vol. 102, 1932, pp. 33-42.

16 Vanderburg, William O., Methods and Costs of Mining Ferberite Ore at the Cold Springs Mine, Nederland, Boulder County, Colo.: Inf. Circ. 6673, Bureau of Mines, 1932, 15 pp.

17 Corwan, J. B., Mining Methods of the Molybdenum Corporation of America at Questa, N. Mex.: Inf. Circ. 6514, Bureau of Mines, 1931, 15 pp.

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that on the average 60 percent of the material broken is rejected as waste by sorting and screening and is left in the stopes. In any event it is unnecessary to go outside the stopes for filling material.

At the Block P mine, Hughesville, Mont., horizontal cut-and-fill stoping is employed. Selective blasting and hand-sorting are practiced to get a high-grade product and minimize loss of ore in the waste.[18] More waste is produced than is required to fill the stopes. Where the ore and waste occur in alternate bands they are blasted together, and the waste is sorted by hand. Where the ore occurs as a single strong band in the vein the waste is blasted first and then the ore. Where the ore is weak and in a single band the ore is blasted first and then the waste.

At the Champion mine a sublevel, inclined cut-and-fill stoping system is now employed.[19] Here about 40 percent of the broken rock is sorted out as waste in the stopes. Additional filling is provided by breaking into the old fill on the level or sublevel above at the top or brow of the inclined stope slice (fig. 2). The method of securing and placing sand filling which was formerly used at this mine will be described later.

Where insufficient waste is broken in the stopes to furnish the required amount of fill other sources of supply must be found. At the Argonaut mine, Jackson, Calif., filling is obtained by driving inclined chambers into the hanging wall[20] or, if the hanging wall is weak and tends to cave, by driving crosscuts into the foot wall (fig. 3). Square-set stoping is employed.

At the Page mine, Page, Idaho, some sorting is done in the stopes, and additional filling is obtained by driving crosscuts into the footwall of the stope.[21] These crosscuts are started about 5 by 7 feet in cross-section and are enlarged to 8 by 12 feet at a distance of 25 to 30 feet from the stope. Waste from the crosscuts is placed in the fills by a drag scraper operated by a single-drum tugger hoist.

At the Central-Eureka mine on the Mother Lode in California waste filling is obtained chiefly by driving chambers into either the hanging or foot wall of the stope.[22] Such openings have an exploratory value, and the strongest point in the wall is selected to avoid caving. They are started as small in section as possible to avoid seriously weakening the stope walls and are enlarged away from the stope. They are usually driven as raises inclined at about 50°. If development work on the level above produces rock too low in grade for the mill this material is dropped into the chute compartment of the ventilation raise and used for stope filling.

At the Bunker Hill & Sullivan mine, Kellogg, Idaho, square-set stopes are started on the hanging-wall side in wide ore, and the first square-set floors on the hanging-wall side are filled with waste obtained by extending the sets on that side into the wall (fig. 4).

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18 Vanderburg, W. O., Mining Methods at the Block P Mine of the St. Joseph Lead Co., Hughesville, Mont.: Inf. Circ. 6416, Bureau of Mines, 1931, 14 pp.

19 Mendelsohn, Albert, Mining Methods and Costs at the Champion Copper Mine, Painesdale, Mich.: Inf. Circ. 6515, Bureau of Mines, 1931, 15 pp.

Mendelsohn, Albert, and Jackson, Charles F., The Sublevel Inclined Cut-and-Fill Stoping System: Trans. Am. Inst. Min. and Met. Eng., vol. 102, 1932, pp. 43-58.

20 Vanderburg, W. O., Mining Methods and Costs at the Argonaut Mine, Amador County, Calif.: Inf. Circ. 6311, Bureau of Mines, 1930, 14 pp.

21 Berg, J. E., Mining Methods at the Page Mine of the Federal Mining & Smelting Co., Page, Idaho: Inf. Circ. 6372, Bureau of Mines, 1930, 8 pp.

22 Spiers, James, Mining Methods and Costs at the Central-Eureka Mine, Amador County, Calif.: Inf. Circ. 6512, Bureau of Mines, 1931, 12 pp.

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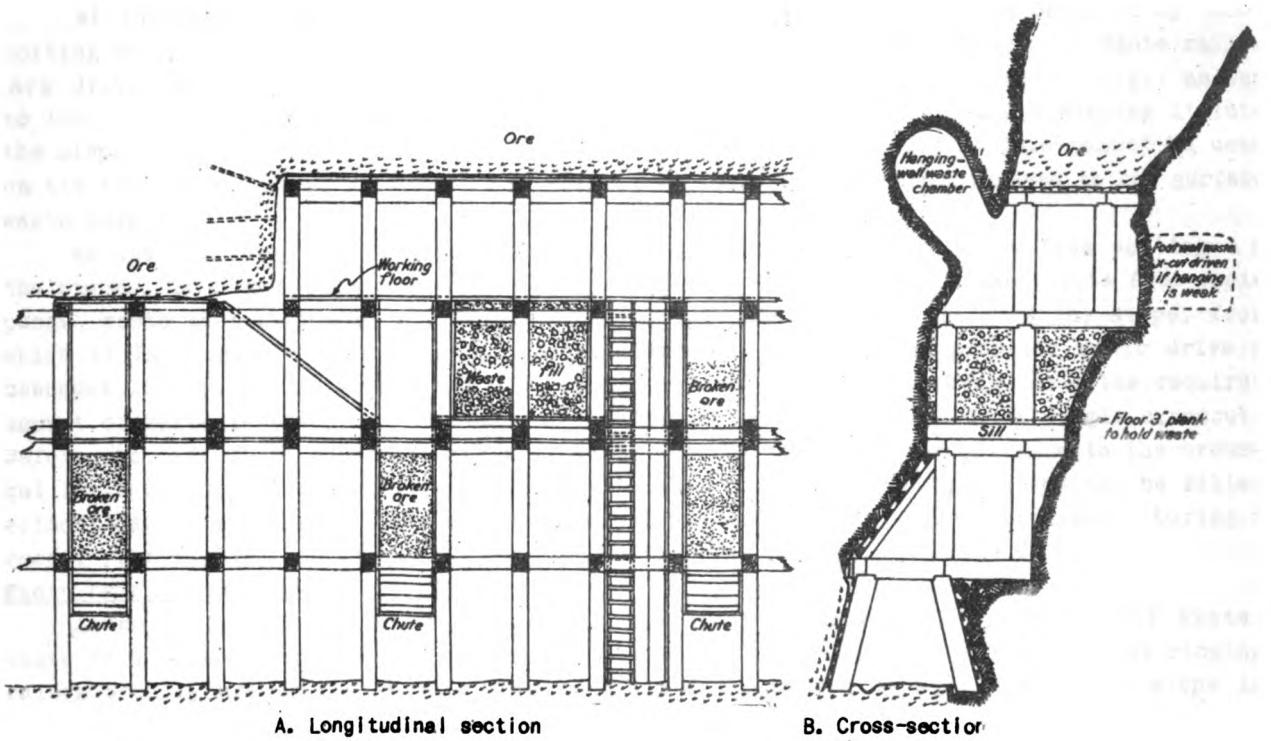

Figure 3.— Vertical stope sections in a narrow vein, Argonaut mine.

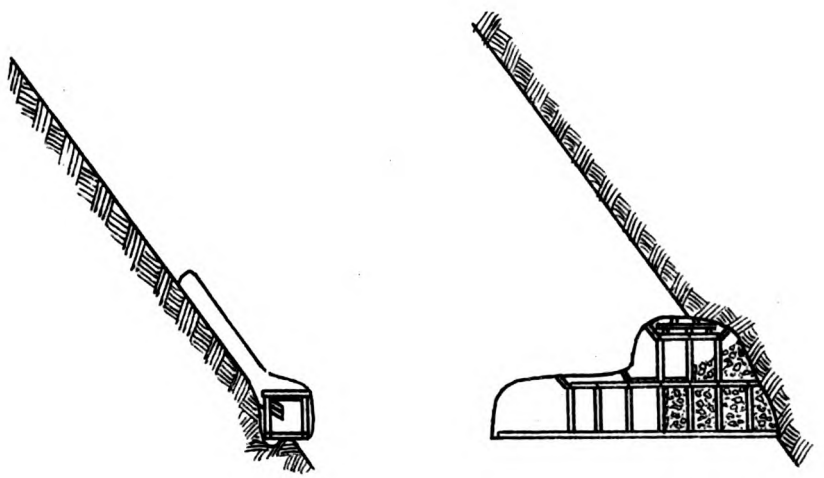

Figure 4.— Starting a stope, Bunker Hill & Sullivan mine.
Sets extended into wall for filling material.

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At the Morning mine, Mullan, Idaho, waste for filling the stopes is obtained by hand-sorting in the stopes or by driving waste raises or crosscuts into the walls.[23] Waste raises are driven on about a 45° slope, and crosscuts are driven horizontally and at right angles to the vein. Scrapers are used for removing waste from the crosscuts and conveying it into the stopes. Additional waste is supplied from development faces; but if this cannot be used on the level where it is produced it is hoisted to the main tunnel and trammed to the surface waste dump.

At the McIntyre mine, Schumacher, Ontario, waste filling is obtained from sorting in the stopes, development work, and special waste stope.[24] In certain areas remote from waste passes waste must be broken locally by driving crosscuts into the walls of the stope, from which it is dragged by a scraper or shoveled into the stope. The practice is to drive a crosscut 16 feet into the wall and then to advance and widen by slabbing until the required amount of waste is obtained. As much as 2,000 tons have been broken in a single crosscut. Before the next slice of ore is taken from the back of the stope the entrance to the crosscut is lagged off, and if the crosscuts are located carefully an entire stope can be filled without caving the walls. This method is expensive and retards stope operations. During a recent year 19,940 tons of waste were supplied in this manner.

Waste from Sources Outside the Stopes

At many mines it would be unsafe to drive openings into the stope walls for waste; waste from other sources must therefore be provided. In cut-and-fill and square-set stoping raises usually are driven through from level to level before or at the time the stope is started. These raises are used for ventilation and for handling supplies, as travelways, or for introducing waste filling. Often they are divided into 2 or more compartments, 1 of which is used exclusively as a waste pass.

Although it is sometimes possible to break waste above these raises in underground stopes or surface gloryholes and convey it by gravity through a system of main and branched raises directly to the stope without intermediate handling, it more often is necessary to transfer the waste in cars on the level above the stope and dump it into the stope raises.

At the Teziutlan mine in Mexico waste for filling is obtained by breaking caving stations at the tops of raises above the orebody.[25] When lower levels are worked waste can be trammed directly to chutes for delivery to the workings below; waste from development work will also be handled in this manner.

In many instances waste from development faces supplies most of the filling. Normally mines are developed from the top downward on successively lower levels, and most of the development work is on levels below the stopes. Most of the waste must therefore be hoisted to the surface or to levels above the stopes to be filled. If the shaft is kept busy hoisting ore, men, timber and other supplies, it may be overtaxed when large quantities of waste must be handled also, particularly if storage room for waste is inadequate and slack periods in shaft operation cannot be employed to advantage for hoisting waste.

In mines using filled-stope methods it would be advantageous if they could be developed and worked from the bottom upward or at least if blocks of several levels each could be worked in this way. Where there is ample capital for development in this manner and the ore deposit is regular and persistent enough so that its continuity for a few hundred feet below

23 Wethered, G. E., and Coady, Leo J., Mining Methods at the Morning Mine of the Federal Mining & Smelting Co., Mullan, Idaho: Inf. Circ. 6238, Bureau of Mines, 1930, 13 pp.

24 Skavlem, H. G., Mining Methods and Costs at the McIntyre Porcupine Mines, Ltd., Schumacher, Ontario: Inf. Circ. 6741, Bureau of Mines, 1933, 18 pp.

25 Herivel, Ernest Ph., Mining Methods and Costs at the Teziutlan Copper Mine of the Mexican Corporation, S. A., Teziutlan, Puebla, Mexico: Inf. Circ. 6736, Bureau of Mines, 1933, 15 pp.

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developed levels can be predicted with some confidence, this procedure may warrant serious consideration. Not only would it simplify and cheapen the cost of procuring, handling, and placing waste, but under certain conditions it would make the stope and walls more stable.

Before skips came into general use for hoisting ore and waste it was customary to hoist development waste on cages to the levels where it was needed and tram the original cars to the waste raises. This practice is still used to a considerable extent where the shafts are equipped for cage hoisting.

In cut-and-fill stoping and filled square-set stoping where the ground is heavy fill must be supplied promptly in the quantities needed, or stope operations will be delayed. If development waste is hoisted on cars and is derived from lower levels prompt delivery of waste may interfere with hoisting of ore and handling of drill steel, timber, and other supplies and may complicate the haulage system. Loaded cars must be moved from the development levels soon after they are filled or else a large number of cars and ample siding facilities must be provided. This time may not coincide with the time when waste is required in the stopes - a further complication. The advantage of ample and conveniently located storage room for waste in the form of large-capacity waste passes, gloryholes, or worked-out stopes is generally appreciated by operators of mines where large quantities of waste filling are required.

At the Pecos mine part of the filling is development waste. In development work in waste a side-dump car of 18 cubic feet capacity is used[26] (fig. 5); it was adopted for convenience in handling waste. By the time some of the present levels are used extensively for waste haulage many of the drifts will have squeezed enough to decrease the clearance seriously. Then the side-dump car will be more convenient than the end-dump type, which must be uncoupled and turned in order to dump it.

At the Silver King Coalition mine 15 to 20 percent of the material broken in the stopes is sorted underground as waste and returned to the stopes for fill.[27] If the waste thus obtained is not enough to fill a stope waste drifts and raises are driven in places that have merit as prospects or as ventilation or haulage openings. They are 5 by 8 feet in section and are near the stopes to be filled.

At the Ground Hog mine, New Mexico, hoisting is done in the new shaft with single-deck cages operated in balance. This method is preferred to skip hoisting because several classes of ore must be handled and waste must be transferred from level to level underground.[28]

In recent years many operators have found it more convenient and economical to hoist all development waste to the surface in skips or to a level above the active stopes and dump it into a common waste pass. This entails the construction and use of separate waste pockets at the shaft on some or all levels or else cleaning the ore pockets of ore periodically and using them temporarily for waste. The main waste pass roughly parallels and is close to the shaft, with chutes for drawing off waste and chutes into which waste may be dumped on each level. Other arrangements may be provided, depending upon where the waste originates and where it is to be used. Thus a number of auxiliary waste-transfer passes extending over two or more levels may be located at convenient points in the mine to take care of the waste.

At the McIntyre mine, Schumacher, Ontario, a waste pass driven at 50 to 55° inclination extends from the 1,250 to the 2,375 level (fig. 6). A connection with a deflecting chute

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26 Matson, J. T., and Hoag, C., Mining Practice at the Pecos Mine of the American Metal Co. of New Mexico: Inf. Circ. 6368, Bureau of Mines, 1930, 21 pp.

27 Dailey, M. J., Mining Methods and Costs of the Silver King Coalition Mines Co., Park City, Utah: Inf. Circ. 6371, Bureau of Mines, 1930. 12 pp.

28 Richard, F. W., Mining Methods and Costs at the Ground Hog Unit, Asarco Mining Co., Vanadium, N. Mex.: Inf. Circ. 6377, Bureau of Mines, 1930, 13 pp.

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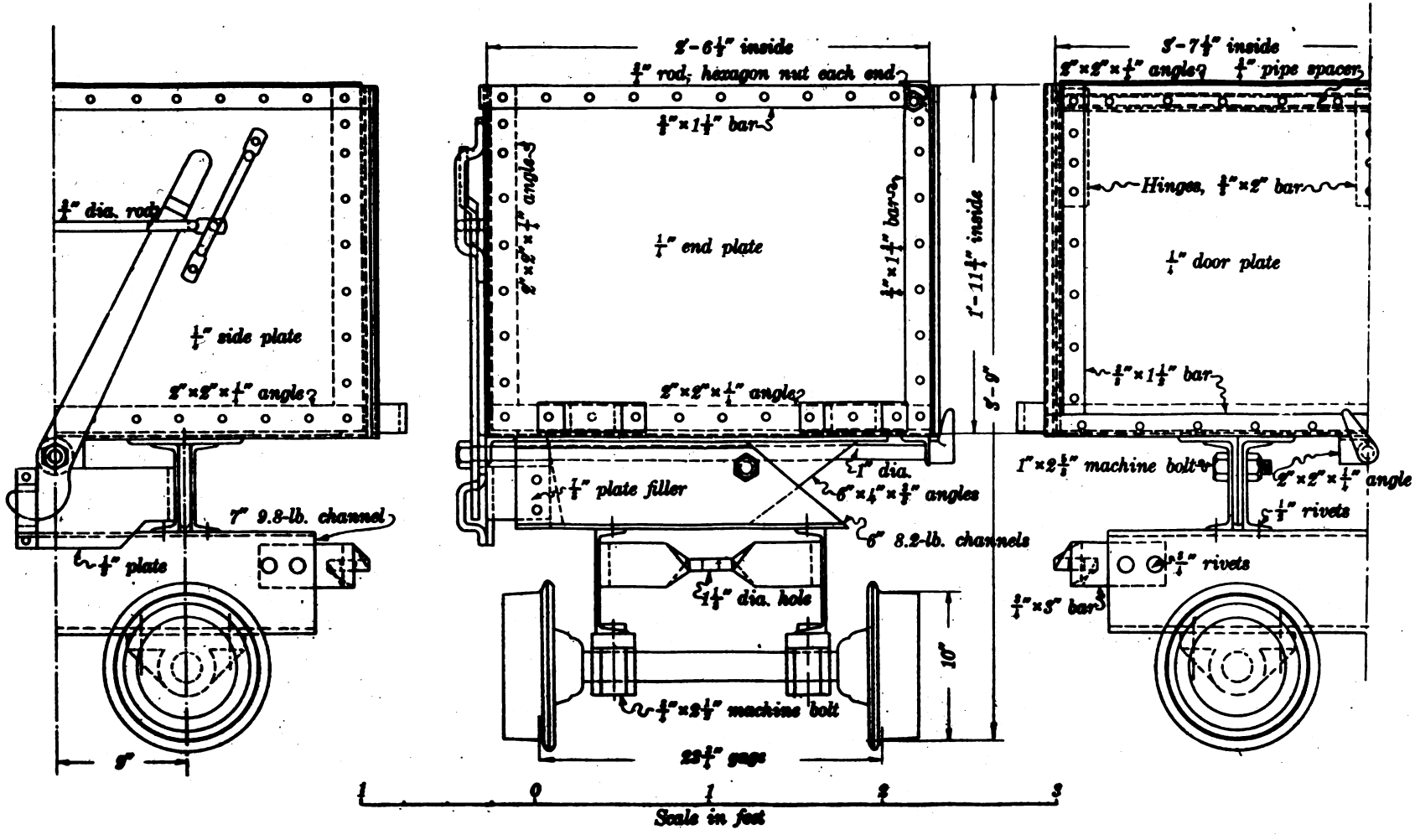

Figure 5.—18-cubic foot side-dump car, Pecos mine.

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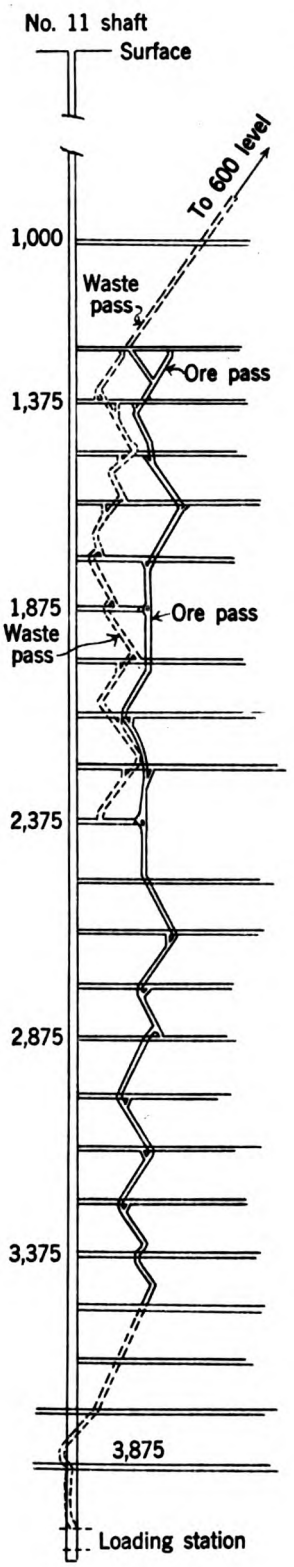

Figure 6.—Ore- and waste-pass systems, McIntyre mine.

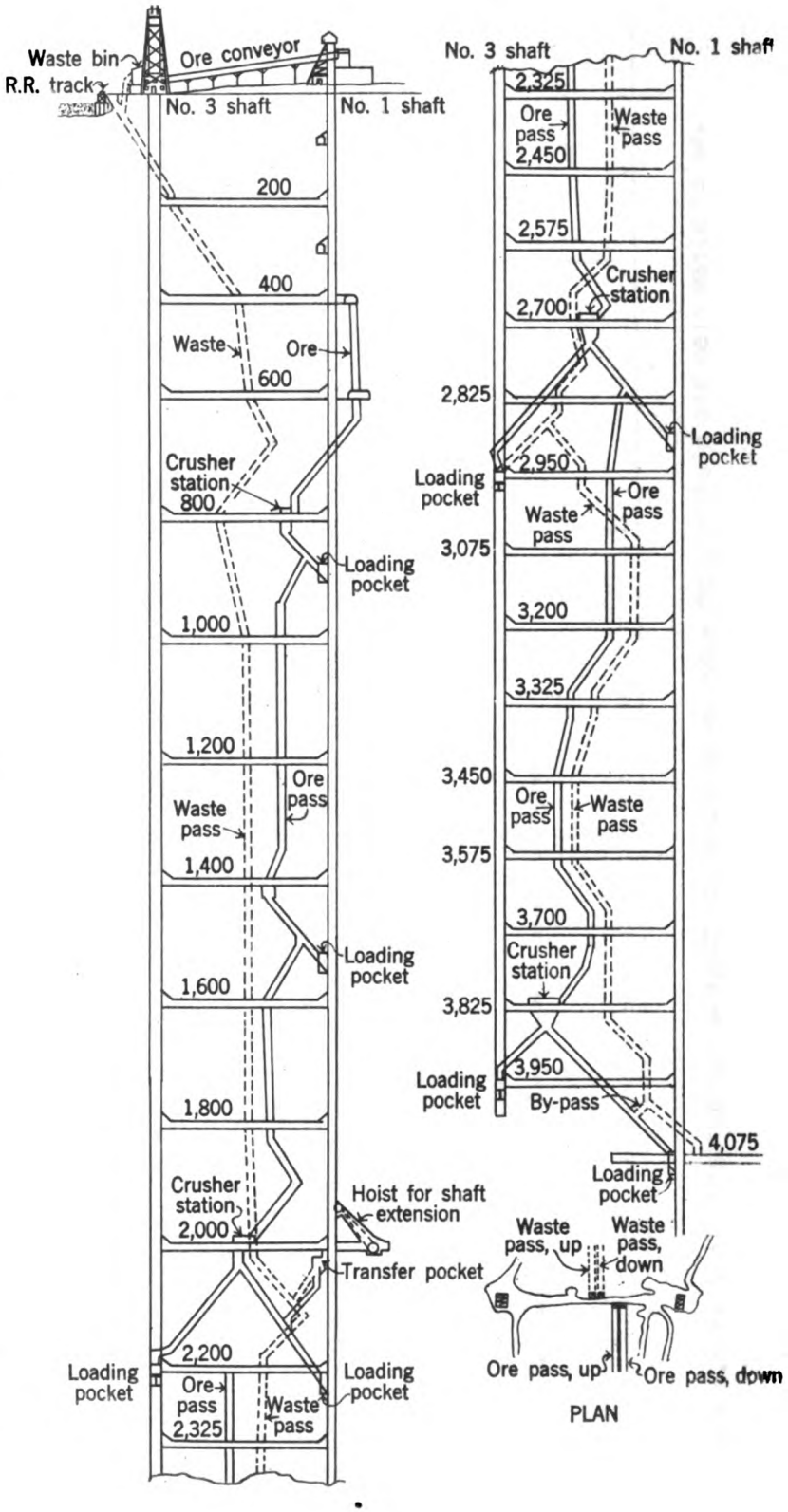

Figure 7.—Ore- and waste-pass systems, Lake Shore mine.

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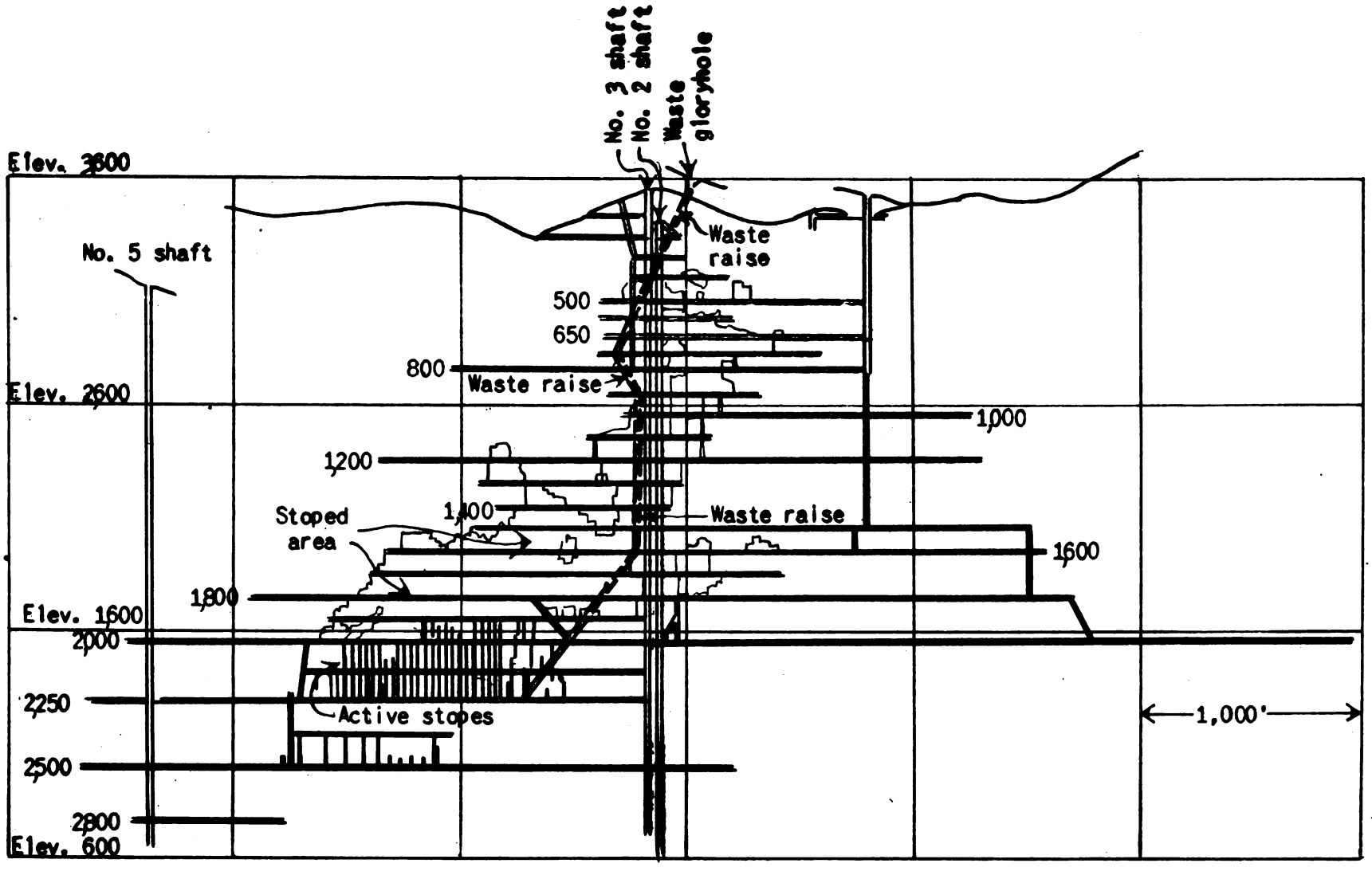

Figure 8.- Partial longitudinal projection, Magma mine, showing gloryhole and main waste raise.

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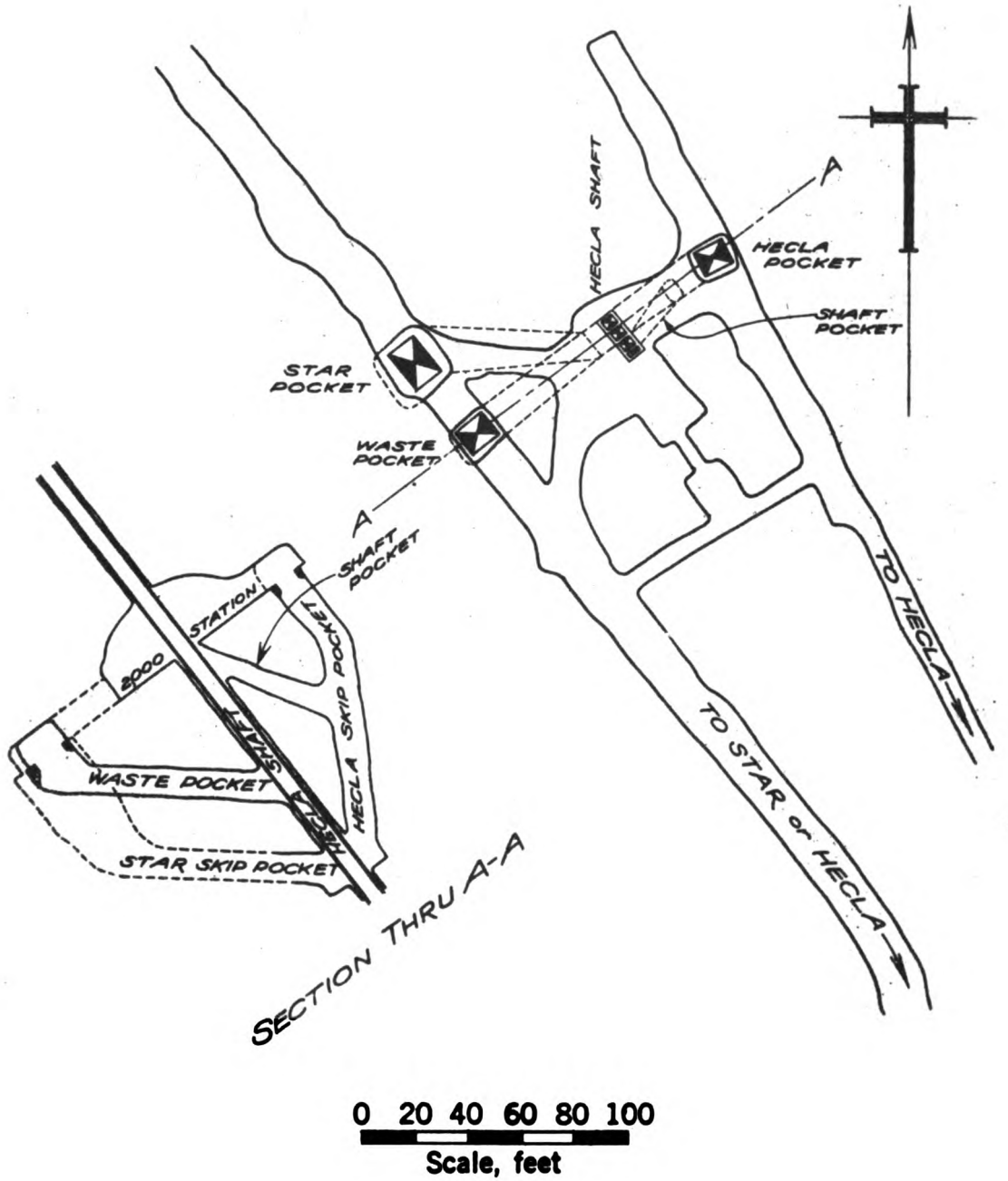

Figure 9.— Arrangement of skip pockets on 2,000 level of the Hecla for handling ore and waste from Star and Hecla mines.

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between the waste and ore passes at the 1,250 level allows the pass above this level to be used for either ore or waste.[29] A draw-off chute and control chutes are built on each level so that waste can be either drawn from or dumped into the pass on any level.

At the Lake Shore mine, Kirkland Lake, Ontario, a "dog-leg" waste pass connects no. 1 and 3 shafts, which are about 300 feet apart, and extends from the surface to the lowest stoping levels; each leg of the pass is driven at about 55° in the opposite direction from the leg above and the one below (fig. 7). Waste may be drawn from or dumped into the pass in the crosscuts connecting the two shafts on each level. A circular steel hopper at the surface receives waste hoisted in skips in no. 3 shaft, whence it can be either diverted to the waste pass or drawn off into trucks for disposal on the surface.

At the Magma mine, Superior, Ariz., about 50 percent of the waste used for filling comes from the waste gloryhole on the surface.[30] This gloryhole is near no. 2 shaft and is connected to the various levels by a main waste raise 8 by 8 feet in cross-section. Development waste hoisted in no. 2 shaft is directed through raises into the main waste pass (fig. 8). Development waste hoisted in no. 5 shaft is handled in small cars and is dumped on levels where it is needed for stope filling.

At the Hecla mine, Burke, Idaho, Hecla ore, Star ore, and waste are handled through the Hecla shaft.[31] These products are taken from their respective pockets in the shaft and hoisted in the skip to bins at the collar; here they are diverted to their proper bins by chutes. All waste from levels above 1,600 is placed in a rock raise connecting with no. 3 tunnel to be drawn for stope filling on levels below. Waste from the 1,600 level is dumped directly into chutes leading to the 2,000-level stopes. Any waste from the 2,000 level or below is dumped in the 2,000-level waste skip pocket, hoisted in skips to the waste bin on the surface, and taken by motor either to the top of the waste raise in no. 3 tunnel or to the surface-tramway waste bin. When sinking from the 2,000 to the 2,800 level the pocket on the north side of the shaft, originally for Hecla ore, was used for waste, the broken material from the shaft being dropped into the shaft pocket. The two pockets on the south side of the shaft were used for Hecla and Star ore during this period. Figure 9 shows the pocket arrangement on the 2,000-foot level for handling ore and waste from the Star and Hecla mines.

At the Black Rock mine, Butte, Mont., skip pockets are built on each level with small waste pockets, in the upper half of the ore pocket. Rock dumped from the skip is diverted into ore or waste bins by air-operated doors.[32]

At the Bunker Hill & Sullivan mine, Kellogg, Idaho, stope filling is essential to the vertical-slice system of square-set stoping, and a supply must be available at all times.[33] The waste is derived from exploratory drifts and crosscuts, from sinking no. 1 shaft, and from raising no. 2 shaft. If necessary, waste raises are driven into faulted zones where caving can be utilized. For storage and distribution of this waste a series of connected raises known as the "Newgard" raise has been driven from no. 17 level to the Kellogg tunnel. Waste can be stored in the raise below any level or withdrawn from the section above for distribution. It is transported to and from the Newgard raise by the ore train drawn by a storage-battery locomotive.

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29 Skavlem, H. G., Mining Methods and Costs at the McIntyre Porcupine Mines, Ltd., Schumacher, Ontario: Inf. Circ. 6741, Bureau of Mines, 1933, 18 pp.

30 Snow, Fred W., Mining Methods at the Magma Mine, Superior, Ariz.: Inf. Circ. 6168, Bureau of Mines, 1929, 32 pp.

31 Foreman, Chas. H., Mining Methods and Costs at the Hecla and Star Mines, Burke, Idaho: Inf. Circ. 6232, Bureau of Mines, 1930, 21 pp.

32 McGilvra, D. B., and Healy, A. J., Methods of Mining at the Black Rock Mine, Butte & Superior Mining Co., Butte, Mont.: Inf. Circ. 6370, Bureau of Mines, 1930, 16 pp.

33 Brown, U. E., Mining Methods of the Bunker Hill & Sullivan Mining & Concentrating Co., Kellogg, Idaho: Inf. Circ. 6407, Bureau of Mines, 1931, 9 pp.

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At Cananea, Mexico, waste for filling the square-set cut-and-fill stopes comes from several sources. A small amount, averaging about 200 tons a day (1929), comes from development work. This is hoisted to the 450 level on cages, dropped in a pocket there, and hauled to one of the waste-transfer raises.[34]

At the Campbell mine, Warren, Ariz., inclined cut-and-fill stoping is employed, and the demands for waste fill are extremely variable.[35] Ample storage capacity is therefore desirable and is provided by a series of storage raises which directly, or through a short transfer, can in a short time, supply a large amount of waste to any given stope. Figure 10 shows the system of storage raises. Waste is obtained from development headings, and an attempt is made to balance the stoping and development work. No waste is handled in the shaft except between levels and from isolated areas.

Waste filling from special waste stopes.- A good example of waste breaking in special waste stopes is furnished by the practice at the McIntyre mine.[36] Waste rock is used exclusively for stope filling. There are five sources of supply: (1) Development and shaft sinking, (2) sorting in stopes, (3) old fill from finished stopes, (4) waste crosscuts driven into the stope walls, and (5) regular waste stopes. About 250 tons per day are obtained from the first three, leaving the fourth and fifth to supply the remainder.

An area about 100 by 200 feet in soft altered porphyry was prepared for mining by caving. A large tonnage was obtained, but with height the ground was found to be silicified and broke in large blocks. The resultant necessary chute blasting decreased the daily tonnage. A similar scheme was tried in a shattered diabase dike about 15 feet wide. A considerable tonnage was obtained, but the method was not entirely satisfactory. A block of ground adjacent to the main waste-pass system was therefore laid out as a sublevel stope and is now being mined. It is 270 feet long, 110 feet wide, and 175 feet high. (See fig. 11.) A 9- by 9-foot drift was driven through the center of the block and a grizzly level established 30 feet above the rail; 6 1/2- by 5-foot sublevels were driven from the main waste pass to the end of the area, 25 feet apart vertically, and a shrinkage stope 110 feet long, 24 feet wide, and 147 feet high was mined across the end. Since then all muck has been obtained by slashing floor, roof, and walls of the sublevels. On the average about 200 tons of waste are broken per machine shift at a cost of 10 cents per ton for first-breaking only. It is estimated that 420,000 tons of waste will be broken here.

Waste from surface quarries and gloryholes.- Where large quantities of waste are required for stope filling surface quarries or gloryholes often can be utilized to supply the required waste economically. It is sometimes possible to locate gloryholes over the stope sections in the mine so that the waste can be transferred directly to the stope-fill raises without intermediate handling. In other instances the broken waste falls by gravity into storage raises, whence it is drawn off into cars at various levels for distribution to the stopes.

At the Magma mine[37] about 50 percent of the waste used for filling comes from a waste gloryhole on the surface. An 8- by 8-foot raise was driven to the surface at a point north of the vein and east of no. 2 shaft (fig. 8). About 50 feet above the 200-foot level a bull-

34 Catron, William, Mining Methods, Practices, and Costs of the Cananea Consolidated Copper Co., Sonora, Mexico: Inf. Circ. 6247, Bureau of Mines, 1930, 41 pp.

35 Lavendar, H. M., Mining Methods at the Campbell Mine of the Calumet & Arizona Mining Co., Warren, Ariz.: Inf. Circ. 6289, Bureau of Mines, 1930, 18 pp.

36 Keeley, D. E., The Story of McIntyre, Development and Mining: Eng. and Min. Jour., vol. 134, November 1933, pp. 459-471.

37 Snow, Fred W., Mining Methods at the Magma Mine, Superior, Ariz.: Inf. Circ. 6168, Bureau of Mines, 1929, 32 pp.

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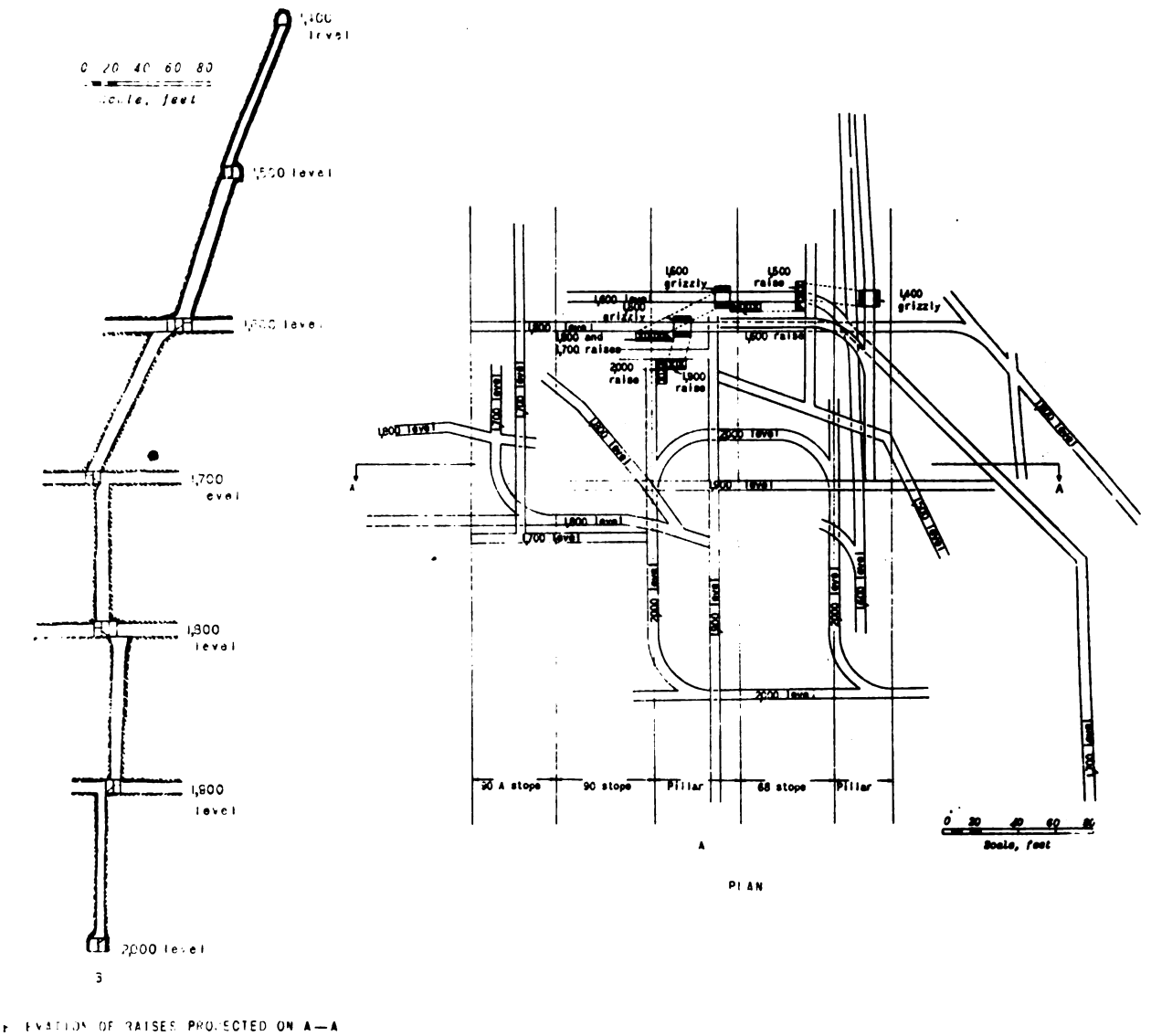

Figure 10.—Waste storage and transfer system, Campbell mine.

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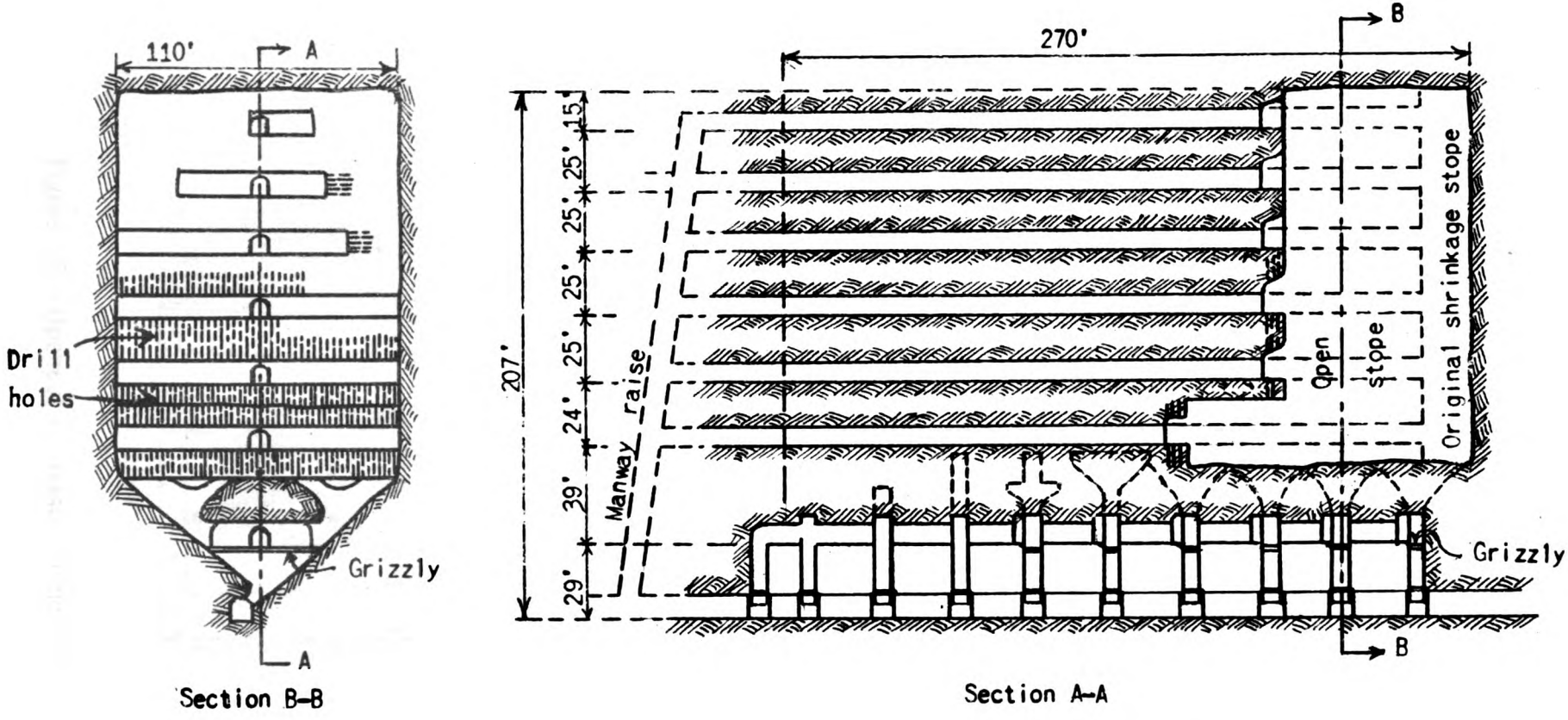

Figure 11.- Sublevel waste stope, McIntyre mine. (Eng. and Min. Jour., November 1933.)

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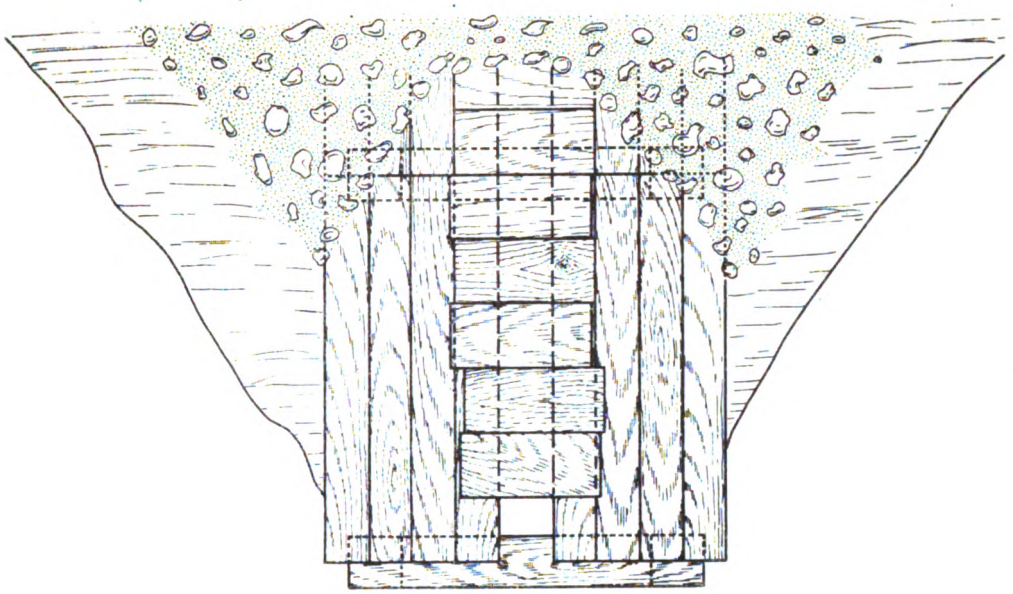

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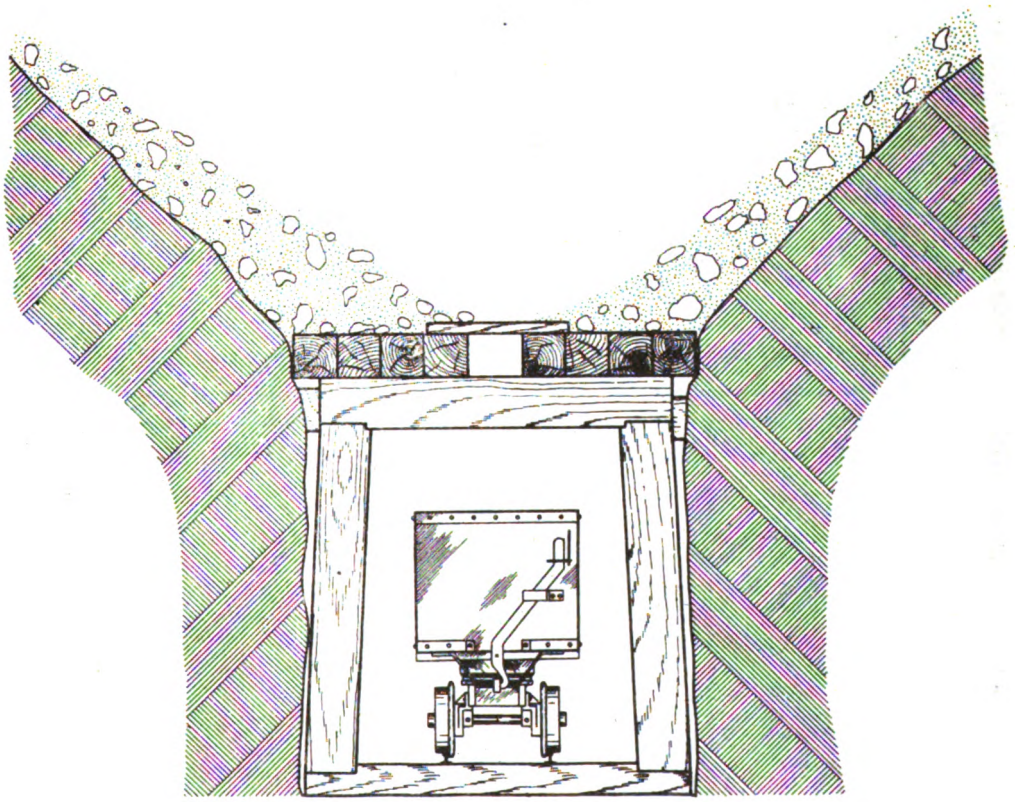

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Figure 12.—Opencut for waste, Tintic Standard mine.

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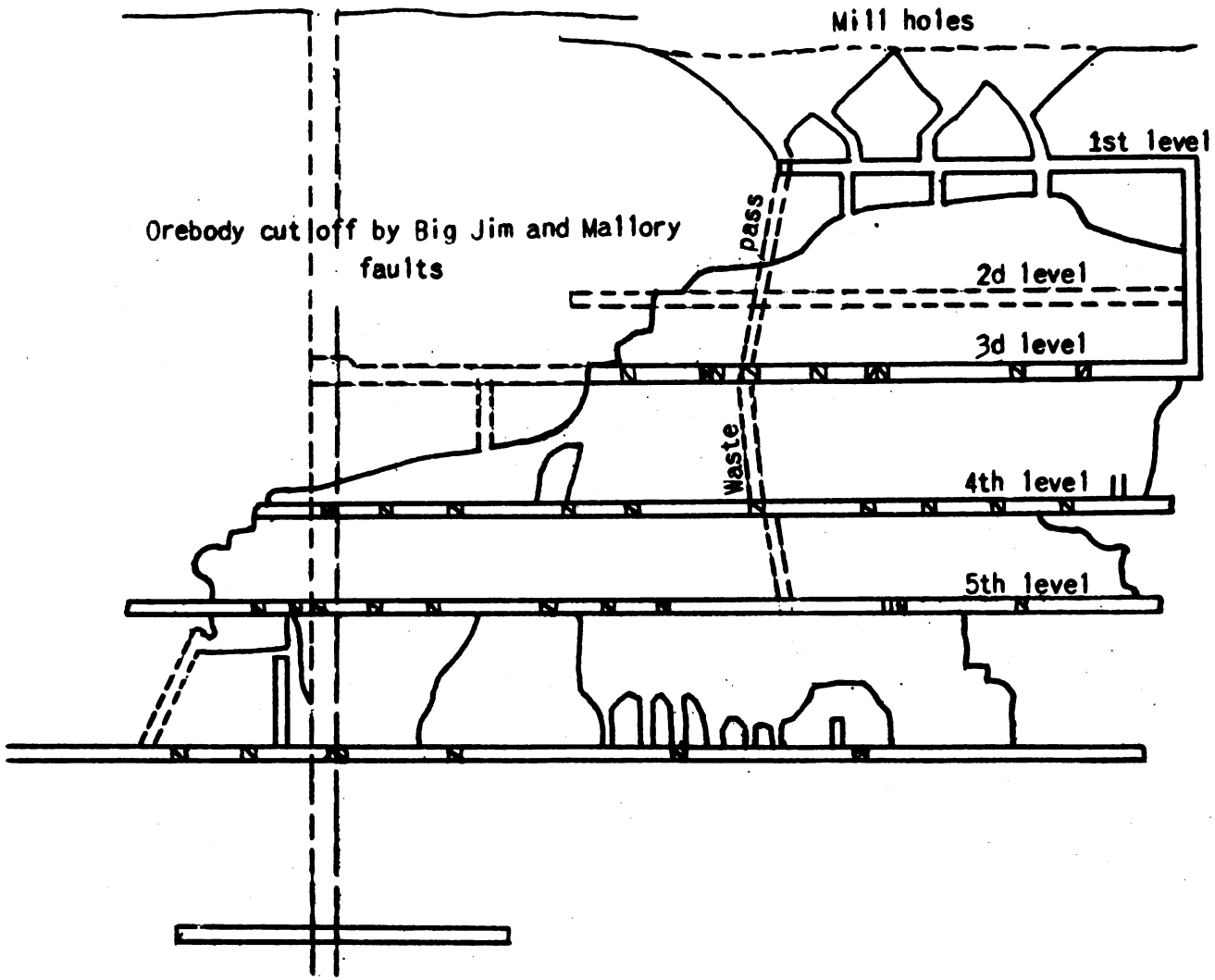

Figure 13.- Longitudinal section through Big Jim stope, United Eastern mine, showing mill holes and waste pass. (Trans. Am. Inst. Min. and Met. Eng., vol. 76.)

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dozing chamber was cut out and a grizzly of 60-pound rails installed. The rails were crossed to form a grid with 16-inch square openings. At the 200 level an 8- by 30-inch jaw crusher driven by a 75-hp. motor was installed. Two men drill and blast in the waste pit and also do the bulldozing and crushing. One miner and a helper are occupied most of the time keeping the waste moving in the waste raise. When the raise hangs up, small charges of explosive on long blasting sticks are used to loosen it. The waste ordinarily runs freely but may pack in the raise if allowed to stand, especially if it is wet. Rain water from the gloryhole is diverted from the main raise just below the pit through a branch raise to the 200 level. Three 3-ton, storage-battery locomotives are used for hauling filling from the waste raises to the stopes. Eight to ten 18-cubic foot, side-dump cars comprise a train. The crew for waste filling comprises a motorman, a loader, and a brakeman.

At the United Verde Extension mine part of the waste filling is obtained from a waste pit. The cost of filling material from the waste pit in 1928 was $0.005 per ton of ore mined.[38]

At the Tintic Standard mine, Tintic District, Utah, an opencut on the surface was used to supply additional waste for filling old open stopes before filled square-set stoping operations were started in adjoining ground.[39] An adit was driven into the side of a hill about 200 feet from the shaft. Ground above the adit was broken, beginning at the entrance, and loaded into cars through chinaman chutes (fig. 12). The waste cars were lowered on the cages to the different levels. In this way filling, along with waste from exploration and development work, was disposed of fairly well after about a year. All labor connected with mining, loading, and delivery of waste from the opencut to the collar of the shaft was contracted for at 20 cents per ton.

At the United Eastern mine, Catman, Ariz., waste for filling stopes in the Tom Reed orebody was obtained from development and from stope-wall raises driven between chutes.[40] These raises often extended 60 feet from the vein where the stopes were widest. They weakened the walls considerably and thus caused trouble when the stopes approached the levels above. Waste was obtained more economically at the Big Jim. This orebody apexed against the Mallory fault about 100 feet below the surface. Raises were driven in ore from the third level to the fault and thence 15 to 20 feet to the waste-distribution level, which was connected by raises to mill holes on the surface (fig. 13). Waste could be dropped directly from the mill holes through three raises into the uppermost stope or through a footwall raise which connected one mill hole to the third, fourth, and fifth levels, from which it was distributed to stope raises below. This system resulted in a much lower filling cost than was obtained at the original property.

At Cananea, Mexico, filling is an important phase of both square-setting and cut-and-fill stoping. As much as 5,000 tons of waste are sometimes required for filling one floor of a cut-and-fill stope.[41] Most of this waste comes from two surface gloryholes, but a small amount is from development work. One gloryhole is over a 500-level tunnel which extends through a small ridge between the Colorada ore bins and the Kirk shaft, and the other is above the 500-level ventilation adit. Rock from any incidental surface excavation in the

38 D'Arcy, Richard L., Mining Practice and Methods at the United Verde Extension Mining Co., Jerome, Ariz.: Inf. Circ. 6250, Bureau of Mines, 1930, p. 11.

39 Wade, James W., Mining Methods and Costs at Tintic Standard Mine, Tintic District, Utah: Inf. Circ. 6360, Bureau of Mines, 1930, 21 pp.

40 Moore, Roy W., Mining Methods and Records at the United Eastern Mine: Trans. Am. Inst. Min. and Met. Eng., vol. 76, 1928, pp. 56-92.

41 Catron, William, Mining Methods, Practices, and Costs of the Cananea Consolidated Copper Co., Sonora, Mexico: Inf. Circ. 6247, Bureau of Mines, 1930, 41 pp.

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mine yards is also used for fill. Other sources of waste were an old dump near the Kirk shaft and the Kirk opencut. A short tunnel runs from the Kirk shaft to the Colorada ore bins. Cuts were started at both portals, and the broken rock was pulled through chutes in the tunnel. Chutes were put in ahead of the advancing cuts at 10-foot intervals and staggered on opposite sides of the drift. The rock is limestone, already heavily shattered, so that it breaks fine. The maximum overburden is 75 feet. Nine or ten men working on day shift only supplied about 310 tons of waste per day at a cost of 13 cents per ton delivered at the chutes.

About half of the waste or 500 tons per day came from the 5-10 gloryhole on a hillside above the 5-10 adit. Two vertical raises 70 feet apart have been put up from the adit to a sublevel 50 feet above, offset there, and continued to the surface. One was 100 and the other 150 feet above the sublevel. After holing through they were enlarged to about 10 by 10 feet above the sublevel to allow large boulders to pass and to 8 by 12 feet below the sublevel for pocket capacity. Grizzlies were installed on the sublevel (fig. 14). The raises were next belled out at the top, and the gloryhole was started. Ten-foot bench holes were drilled downward and blasted into the raise with 40-percent gelatin. The crew comprised a jigger boss and 10 to 20 men, 4 of whom worked part of the time in the bulldozing chambers. The rock is a diorite porphyry which breaks in coarse lumps so that about a quarter of it must be broken on the grizzlies with hammers or pavement breakers or by drilling and blasting. In 1 month this gloryhole produced waste at an estimated cost of $0.098 per ton delivered to the chutes in the 5-10 drift. The labor amounted to 0.229 man-hour per ton (34.9 tons per man-shift), and powder consumption was 0.12 pound per ton.

At the Pilares mine, Nacozari, Mexico, by far the largest part of the filling comes from three large surface gloryholes.[42] In two of these constant mining operations are necessary; in the other the waste is drawn from a large partly mined and filled area in which the rock is now fairly well crushed. The gloryholes lead through a 20-foot-diameter throat to grizzly chambers. The grizzlies are of heavy construction - 10- by 10-inch timbers covered with sheet steel and 80-pound rails - and have 16- by 20-inch openings. Figure 15 shows the waste-pass system (heavy black lines) at this mine.

Development waste originating on any level below the 700, when it cannot be conveniently dumped as fill in a nearby stope, is trammed to the Guadalupe waste system, where it finds its way to control chutes at the ore pockets. At convenient intervals the ore pockets are cleaned, and the waste is hoisted to dumps 50 feet below the 500 level, where by a system of control doors it is diverted back into the Guadalupe waste system to be drawn off at any level where it may be needed. In addition, a large shrinkage stope just above the 1,000 level, which has raise connections to the 700 main-haulage level, is used for auxiliary waste storage. Waste is transferred in 5-ton Western-type cars from waste passes and fill holes on the 700 level to waste dumps on that level and in mine railroad ore cars to the old Pilares waste system, which furnished waste for the stopes in the Pilares orebody at the south end of the mine.

At the United Verde mine, Jerome, Ariz., the material used for filling is waste rock from stripping operations in the shovel pit and waste from underground development work.[43] This waste is delivered to the various levels through two main waste-pass raises, one directly from the shovel pit and the other from the Hopewell haulage tunnel. Because of the distance the waste falls in these raises, which are intentionally kept empty at the top, con-

42 Leland, Everard, Mining Methods and Costs at the Pilares Mine, Pilares de Nacozari, Sonora, Mexico: Inf. Circ. 6307, Bureau of Mines, 1930, 34 pp.

43 Quayle, T. W., Mining Methods and Practices at the United Verde Copper Mine, Jerome, Ariz.: Inf. Circ. 6440, Bureau of Mines, 1931, 31 pp.

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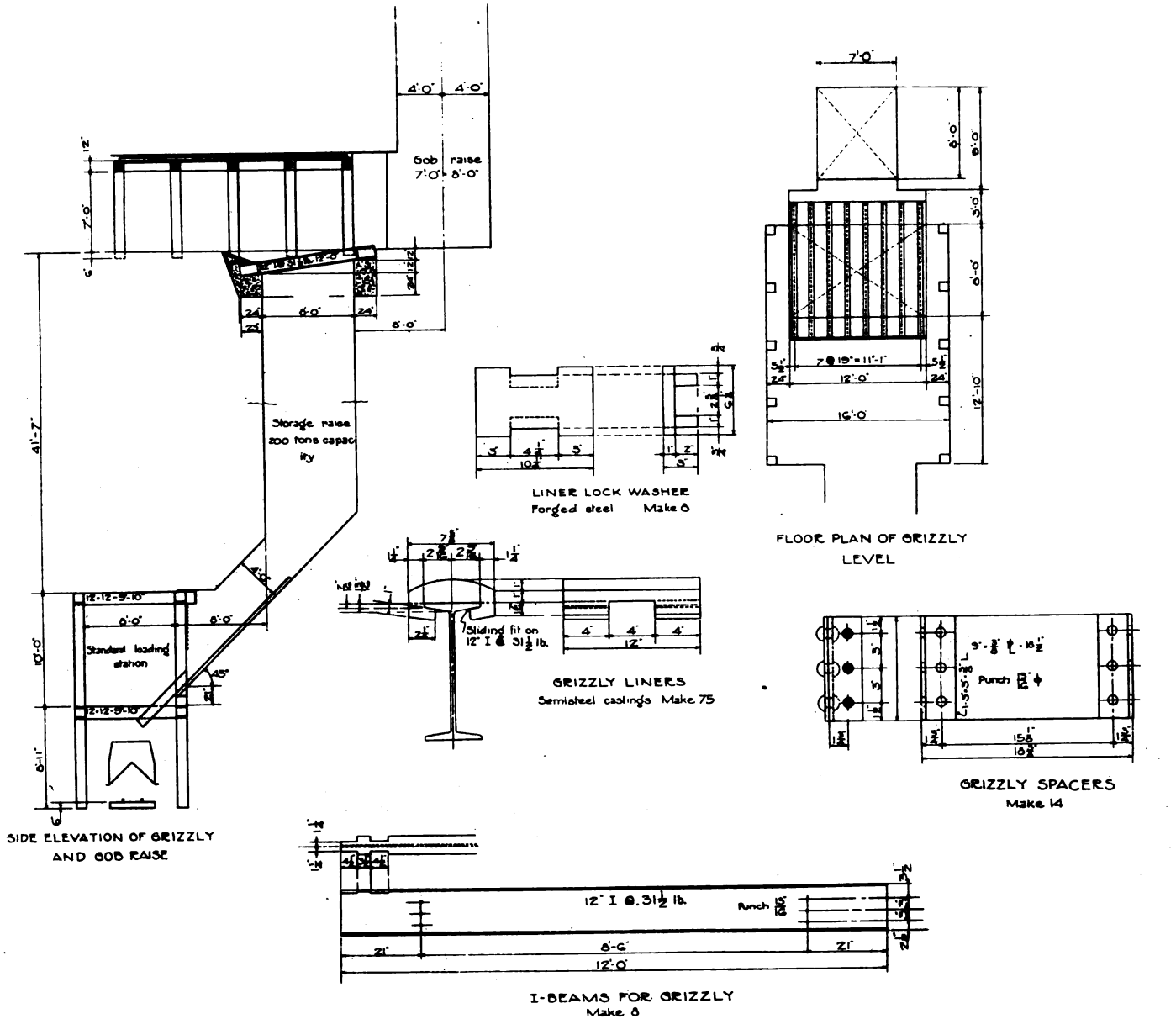

Figure 14.—Grizzly and storage raise, La Colorada mine.

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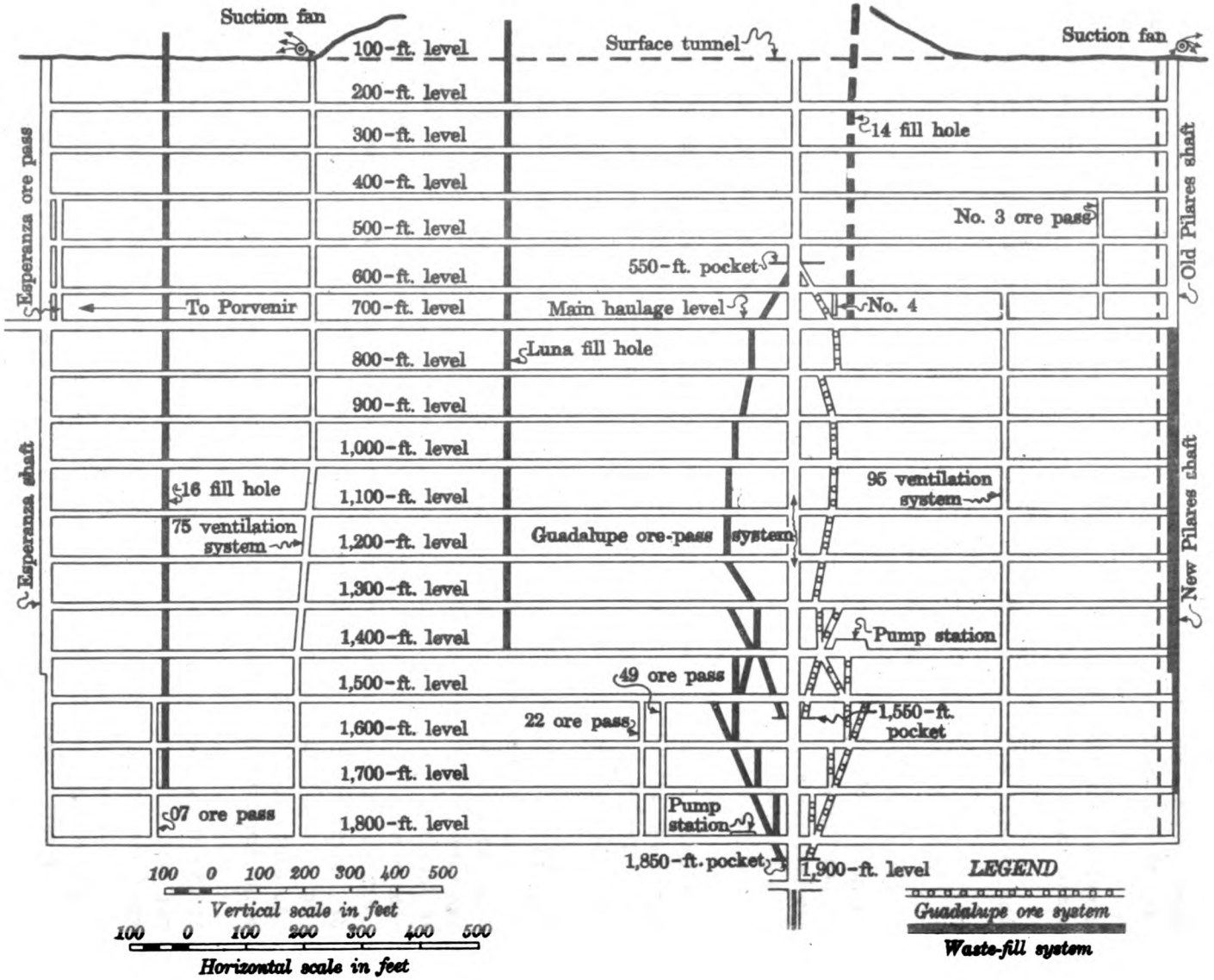

Figure 15.— Diagrammatic longitudinal vertical section showing waste-pass system, Pilares mine.

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siderable crushing action takes place. From the waste passes the waste is trammed to the tops of the stope raises by the same equipment that hauls the ore.

Waste from other sources.- Filling is sometimes drawn from old stopes if the practice does not endanger active mining areas, permanent haulage and ventilation openings, or surface structures. The drawing of waste from old stopes at the Champion mine has already been mentioned.

The Colorada orebody at Cananea was relatively low-grade and narrow above the 500 level; in 1929 a large part of the material drawn from the stope in this section was used for fill in stopes below.

At the Pilares mine, Nacozari, Mexico, some waste is taken from adjacent mined and filled stopes.

Sand and Gravel Filling

The favorable characteristics of sand and gravel for filling have been mentioned previously. In some regions where large glacial or stream deposits exist, sand and gravel may be used to supply the bulk of the filling material. Even though this material must be brought some distance to the mine, it may be the most economical filling, because of its favorable characteristics and the ease with which it may be handled, distributed, and placed in the stopes.

At the Lake Shore mine, Kirkland Lake, Ontario, a sand pit about 16 miles from the mine and alongside the railroad supplies much of the filling material for the stopes. The sand is loaded by power shovel into bottom-dump railroad cars, which are hauled to the mine and dumped into a pocket connecting with the main waste pass near no. 3 shaft (fig. 7). This waste pass has already been described.

At the Hollinger mine, Timmins, Ontario, sand and gravel filling is brought to the mine over an aerial tramway from pits situated about 3 3/4 miles from the mine. The gravel is excavated by power shovel and is delivered to a loading bin or pocket from which it is drawn into buckets, each of which carries a net load of 1,800 pounds. The tramway system consists of one endless rope passing around a terminal sheave at either end and kept in continuous motion. There are 57 steel towers averaging 28 feet in height. The rope speed is 120 yards per minute, and the rated capacity of the system is 125 tons per hour. The buckets dump automatically at unloading towers over raises communicating with the surface. The total cost delivered at the mine is around 20 cents per cubic yard or 15 cents per ton of sand. Waste from development work is also used for back filling. In 1933, 811,000 tons of filling were placed in the mine, and 1,727,102 tons of ore removed from the mine and put through the mill; thus about 0.47 ton of filling was placed per ton of ore milled.

At the Rodbarrow mine in Cumberland, England, beach sand is used for filling;[44] it is sent into the mine through 4-inch pipes connected by Victaulic joints. The pipes are hung in toreholes or in unused shafts. At the collar of each pipe is a concrete hopper, and over the end of the pipe is a wire screen with 1-inch openings. If the sand is near enough to the borehole, it is flushed into the hopper with a hose. Most of the sand now used, however, is loaded into cars with a clamshell bucket and is dumped into the hopper from which it is washed into the pipe by a 2-inch hose with a 1-inch nozzle. The stream normally carries 40 percent solids and 60 percent water; but sometimes this percentage is reversed, or the solids may fall as low as 30 percent. The sand grains are all rounded, and the wear on the pipes is not serious.

44 Eaton, Lutlen, Sand Filling Through Pipes and Boreholes: Trans. Am. Inst. Min. and Met. Eng., vol. 102, 1932, pp. 33-42.

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The feature of the system is the use of compressed air as a booster. The pipe has long-sweep elbows; into some of these 3/4-inch pipe is tapped on the center line of the pipe on the exit side so that the air jet will not impinge upon the wall of the pipe. The 3/4-inch pipe is reduced to 1/8 inch at the end. The compressed air increases the velocity of the stream and keeps the pipe clear of sand, regardless of the gradient. A signal cable is strung through the borehole so that signals can be given for control of the sand. Since the free discharge of air at 70 pounds pressure through a 1/8-inch nozzle is only 19 cubic feet per minute the air consumption is not large, and as the mine is less than 600 feet deep the pumping charge for the water from the fill cannot be large.

Mill Tailings

The use of mill tailings for stope filling at Minas de Matahambre, Pinar del Rio, Cuba, has been described and discussed by Richert[45] and Homer.[46] In 1929 about half of the fill tonnage was made up of sand tailings. The amount of sand used depends entirely upon the amount of development waste that must be disposed of as fill. Briefly, the sand-fill system consists of pumping mill tailings to a 30-foot bowl classifier on the surface near a raise leading into the mine. Figure 16 shows the Matahambre system diagramatically. The slime overflow from the classifier is sent to the tailings pond, and the rake product drops into a hopper. Water is added to the hopper, and the coarse tailings are washed into a 2 1/2-inch special rubber-lined pipe, which is strung through a line of raises from the surface to the 1,200-foot level. The sand is taken through the pipe to the stope to be filled. Before the filling is introduced the cribbed raises and manways are wrapped with a commercial grade of burlap to prevent the sand from washing in between the cribbing.

Two years of experimenting with standard pipe, extra-heavy pipe, special rubber hose, and special rubber-lined pipe proved the last to be by far the best. A standard metal pipe could handle 1,000 tons of sand and extra-heavy metal pipe 2,000 tons before they were worn out, whereas wear on rubber-lined pipe was virtually negligible on straight lines of pipe after the passage of 205,400 tons. One curved length had a small hole worn through at a bend after more than 200,000 tons of sand had passed that point.

The pipe is standard, flanged, 3-inch-inside diameter pipe, in 12-foot lengths with a 1/4-inch rubber lining vulcanized to the inside of the pipe by a special process. The lining extends over the face of the flanges, thus acting as a gasket to prevent sand from wearing its way into the joint between rubber and pipe. Two main lines have handled 35 tons per hour without difficulty; the capacity is apparently still higher. Sand is diverted to any level by taking out a length of pipe in the main line and inserting a curved length which is connected with the branch line; all valves and tees are thus eliminated. The same method is used for connecting stope lines with the branch lines.

The average cost per ton of sand placed in stopes during a 6-month period was: Labor, 10.5 cents; burlap, 4.8 cents; pipe, 7.1 cents; pump, 0.6 cent; power, 2.0 cents; total, 25.0 cents. As no replacement of pipe had been made the actual costs probably did not exceed 20 cents per ton of sand placed. The total reduction in cost per ton of ore mined resulting from the convenience and economy in using sand fill and the increase in production made possible by this system of filling has amounted to over $1 per ton or $350,000 to $400,000 annually during normal operations.

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45 Richert, George L., Mining Methods at Minas de Matahambre, Pinar del Rio, Cuba: Inf. Circ. 6145, Bureau of Mines, 1929, 18 pp.; Filling Stopes with Mill Tailings: Eng. and Min. Jour., Mar. 2, 1929, p. 348.

46 Homer, D. D., Rubber Pipe Lining Minimizes Pulp Abrasion: Eng. and Min. Jour., Oct. 26, 1931, pp. 367-368.

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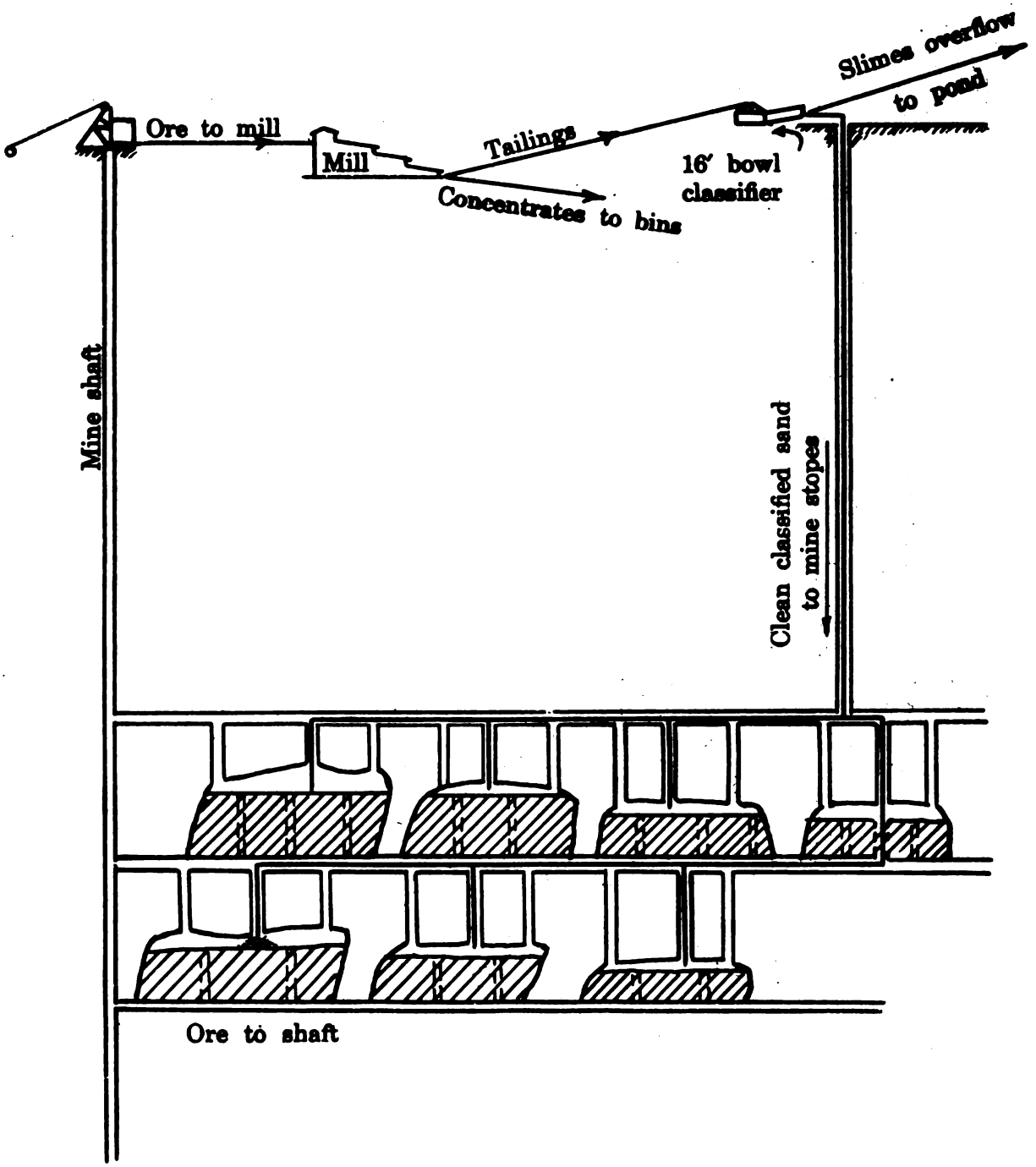

Figure 16.— Flow sheet showing Matahambre system of filling stopes with mill tailings.

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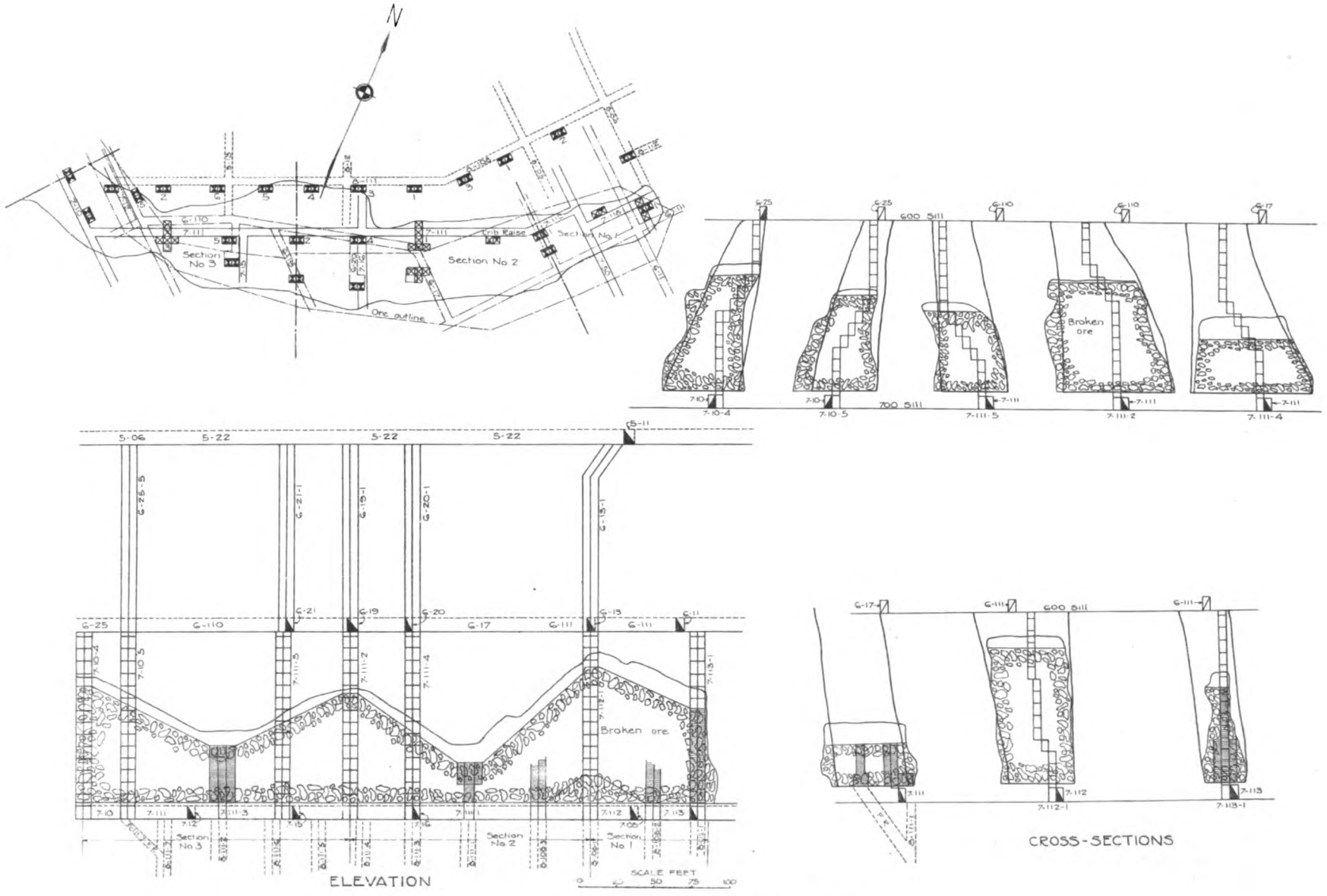

Figure 17.—Filled rill stope in La Colorada mine.

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At the Champion mine, Painesdale, Mich., mill tailings or stamp sand was formerly used extensively to make up the deficiency in waste fill in certain stopes.[47]

The sands were hauled from the mill in 40-ton, bottom-dump cars and dumped into a raise that paralleled no. 4 shaft and connected with all working levels. The sand was drawn from chutes into 1 1/2-ton, bottom-dump cars, usually 6 in a train, and hauled by motor to raises communicating with the stopes below; the raises were used for storage to feed sand-blowing tanks operated by compressed air and located directly underneath the raise.

INTRODUCTION AND PLACING OF STOPE FILL

The method of introducing and placing fill in the stopes depends upon the nature of the filling material, the stoping method, the dip of the vein and other characteristics of the ore deposit, and the distance between fill raises. If stopes are carried horizontally hand or mechanical means must be employed for spreading the fill laterally. If stope backs are carried on an incline steeper than the angle of repose of the filling material the fill runs into place by gravity, and only a small amount of handwork is ordinarily required for leveling it off and, in flat-dipping veins, for filling in the space under the hanging wall where it will not run by gravity. With closely spaced fill raises the filling may be shoveled into place or handled in wheelbarrows; with widely spaced raises it may be necessary to draw the filling into cars and tram it into place.

Water or compressed air, or both, may be used to spread sand filling in flat stopes or to place it at elevations somewhat above the outlet of the fill raise to fill under local caves that may have run up in the back. Power-operated scrapers may be employed to distribute either rock or sand fill in the stopes, to place it under a dangerous back where men cannot work safely, or to drag it up-grade to fill above a level or under high spots in the back of a stope.

Rock Fill

Handling rock fill in inclined stopes is comparatively simple, as most of it can be run into place by gravity. Figure 17, a vertical section of an inclined cut-and-fill stope in La Colorada mine, Cananea, Mexico,[48] shows the waste passes for introducing the fill. Here the ore was 40 to 60 feet thick. The stope was silled to a height of 11 feet on the 700 level by breast stoping, carrying a face the width of the ore and pulling the broken ore to chutes with scrapers. The level was timbered and a bridge cap placed over each set. A floor of 2-inch plank was laid, the extraction chutes were cribbed up to the back, and waste was run in from the 500 level and spread to within 3 feet of the back. Stoping was then begun by taking out ground on both sides of the waste raises in inclined slices 11 feet thick and filling with waste after each cut until the back of the stope had the saw-toothed profile shown in figure 17. Floor is laid on the sloping fill after each filling before mining is started. With so wide a stope the slope of the rills could not be carried steep enough to run the ore into the chutes by gravity or to spread all the fill; scrapers were therefore used to move the ore and spread the fill that would not run by gravity.

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47 Schacht, W. H., Mining Methods of the Copper Range Co.: Trans. Am. Inst. Min. and Met. Eng., vol. 72, 1925, pp. 346-370.

48 Catron, William, Mining Methods, Practices, and Costs of the Cananea Consolidated Copper Co., Sonora, Mexico: Inf. Circ. 6247, Bureau of Mines, 1930, 41 pp.

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At the Campbell mine, Warren, Ariz.,[49] inclined cut-and-fill and semishrinkage stoping are employed for mining the ore. The orebody was divided into a system of alternating transverse stopes and pillars (fig. 18). In general, the plan was to have 2 adjoining stope sections, each 45 to 50 feet wide, separated from the next 2 stoping sections by a pillar 45 feet wide. In laying out the stope and pillar sections it was planned to work both stope sections by cut-and-fill methods. While the stopes are being silled the waste raise is holed to the level above and frequently to the next haulage level 200 feet above. The lead-set posts next the stope on the fill side are 3 inches longer than those on the opposite side to allow for compression of the timber due to settling of the fill. The leads are carried far enough ahead of the fill as stoping advances upward to provide ample height for gob lagging and to give access to the working floor of the succeeding cut. On completion of the lead sets and the slice between, the stope is cleaned out by hand-mucking and drag scrapers. The bottom of the stope is then covered with a timber mat of scrap timber. The lead sets are lagged off on the fill side, and waste is dropped in through the fill raise until it is within 2 or 3 feet of the back of the stope. The natural angle of repose of the fill is 37°, and the back of the stope roughly follows this angle. On completion of the filling 2- by 10-inch sills are laid and covered with 2-inch flooring, and mining is resumed. Each cycle of cut-and-fill is about the same, and the lead sets are raised with the main cut.

At the Pilares mine rill cut-and-fill stoping produced 26 percent of the total output of ore in 1928.[50] It is used where the ore and the walls of the stope are solid; the orebody is fairly regular in shape and has sufficient vertical extent. Figure 19 shows a rill stope in this mine. On the opposite end of the stope from the chute-and-manway raise a waste raise is driven to the level above, through which waste is dumped to fill the stope. An inclined cut 6 feet thick is taken parallel to the angle of repose of the fill, and filling is run in. Succeeding cuts are taken and filled until the toe of the fill reaches the ore chute at the other end of the stope. The back of the stope is cut horizontally at this point to a height of 10 feet to provide sorting space on the grizzlies. An 8-foot cut is then taken parallel to the fill from the bottom to the top of the stope, the chute is raised 8 feet, the stope is again filled with waste, and the cycle is repeated. A floor of 3-inch plank or pole lagging is laid on the fill before the cuts are blasted.

At the United Verde mine, Jerome, Ariz., inclined cut-and-fill stoping has been used in a few special cases.[51] After the stopes have been silled two cuts inclined at 40° are taken at the waste raise, followed by filling; another inclined cut is taken and filled, and so on until the incline is fully established and the toe of the fill has reached the chutes at the opposite end of the stope. A row of square-sets is then placed along the wall over the chutes for protection of the shovelers (fig. 20.) A horizontal cut is next taken from the back, starting from the wall and meeting the incline; the incline is then mined from the bottom up, usually beginning at the center and carrying the bench up as an inverted V. After each cut is broken and the ore removed the new slice is started at the bottom and run at an angle about 3° steeper than the natural angle of repose of the waste fill. Only 5 to 10 feet of floor, as measured on the incline, are placed at a time, and the waste fill is introduced at the top of the incline. This method insures a compact fill under the floor and reduces breakage of the flooring. The fill is dumped into the raise and trammed along the crest of the fill in scoop cars (fig. 21).

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49 Lavendar, H. M., Mining Methods at the Campbell Mne of the Calumet Consolidated Copper Co., Sonora, Mexico: Inf. Circ. 6289, Bureau of Mines, 1930, 18 pp.

50 Leland, Everard, Mining Methods and Costs at the Pilares Mine, Pilares de Nacozari, Sonora, Mexico: Inf. Circ. 6307, Bureau of Mines, 1930, 34 pp.

51 Quayle, T. W., Mining Methods and Practices at the United Verde Copper Mine, Jerome, Ariz.: Inf. Circ. 6440, Bureau of Mines, 1931, 31 pp.

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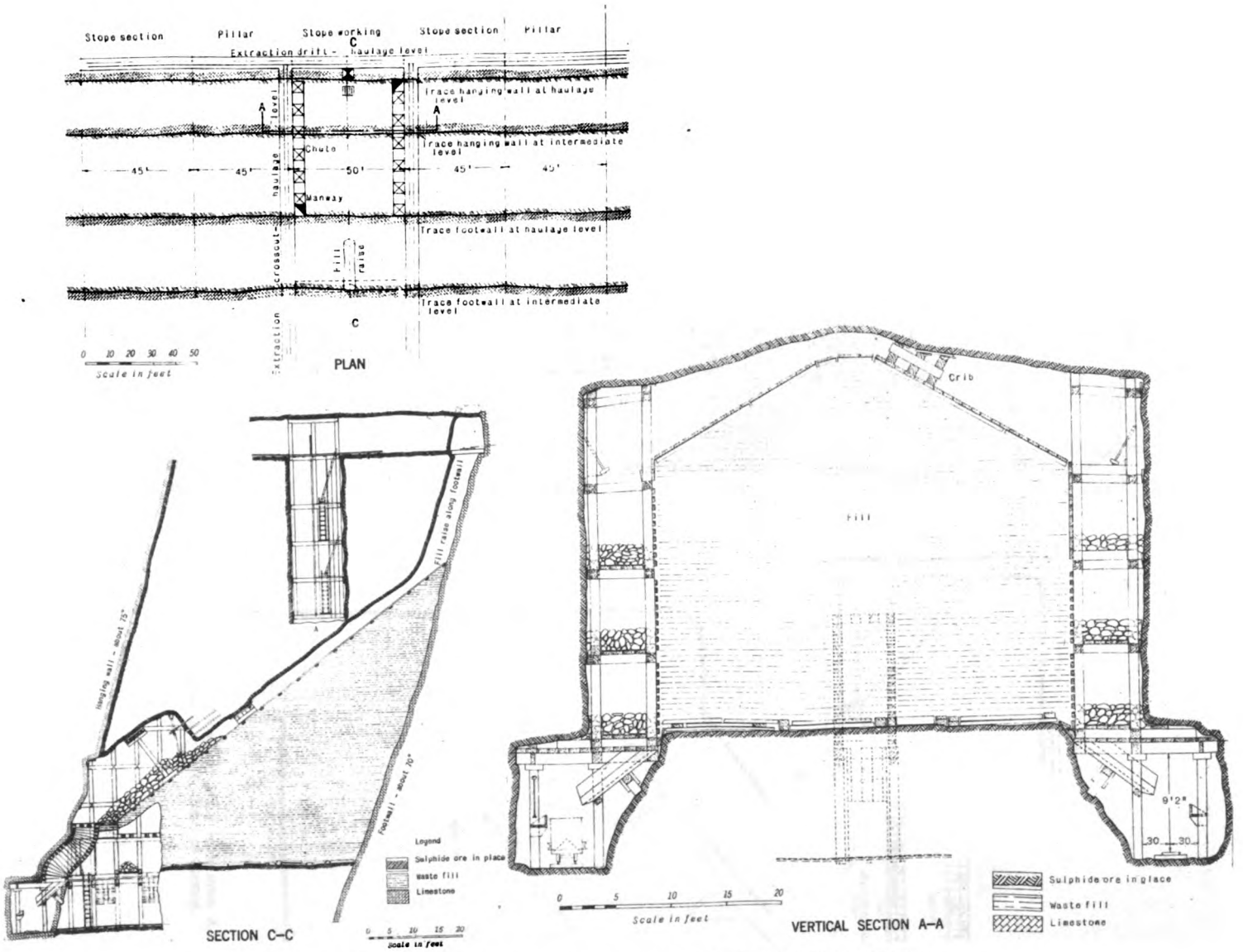

Figure 18.—Double-lead, inclined, flat-bottomed cut-and-fill stope, with fill raise in footwall, Campbell mine.

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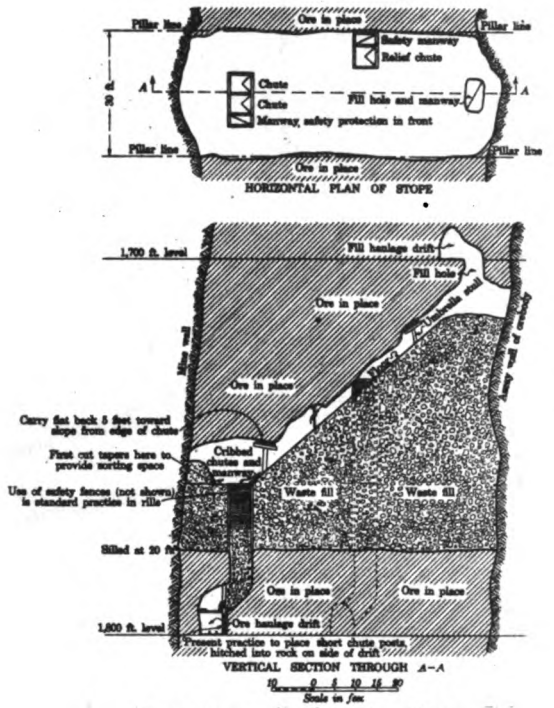
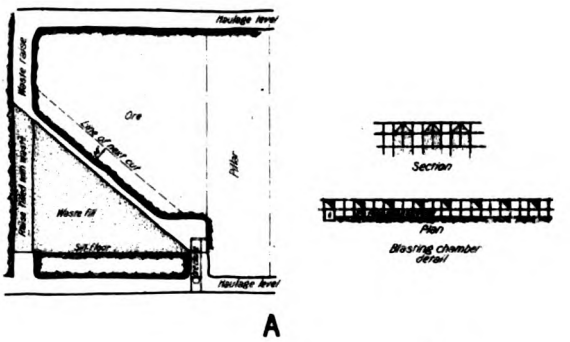

Pillar line
Ore in place
Safety manway
Relief chute
Chute
Chute
Manway, safety protection in front
Fill hole and manway
HORIZONTAL PLAN OF STOPE
1,700 ft. level
Fill haulage drift
Fill hole
Ore in place
Waste fill
Curve flat back 5 feet toward slope from edge of chute
First cut tapers here to provide sorting space
Cribbed chutes and manways
Use of safety fences (not shown) is standard practice in rills
Waste fill
Waste fill
Skilled at 20 ft.
Ore in place
Ore in place
1,600 ft. level
Ore haulage drift
Present practice to place short chute posts, hitched into rock on side of drift
VERTICAL SECTION THROUGH A-A
Scale in feet

Figure 19.— Typical rill section, Pilares mine.



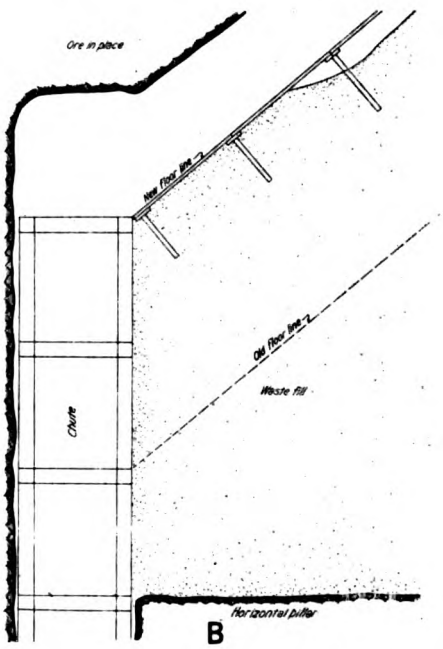


Figure 20.— Rill stoping, United verde mine: A, typical stope section; B, detail of flooring.

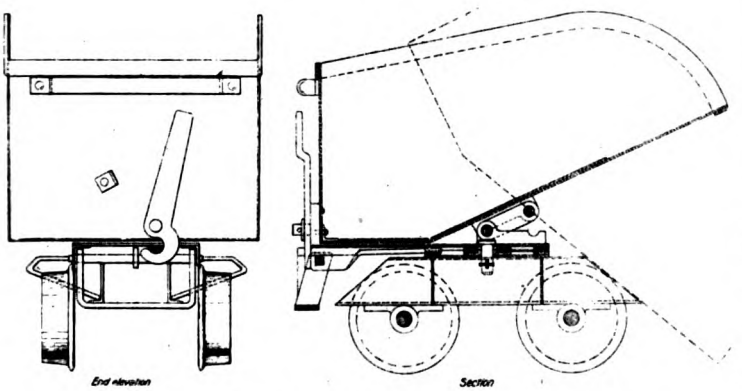


Figure 21.— 18-cubic foot scoop-body car, United verde mine.

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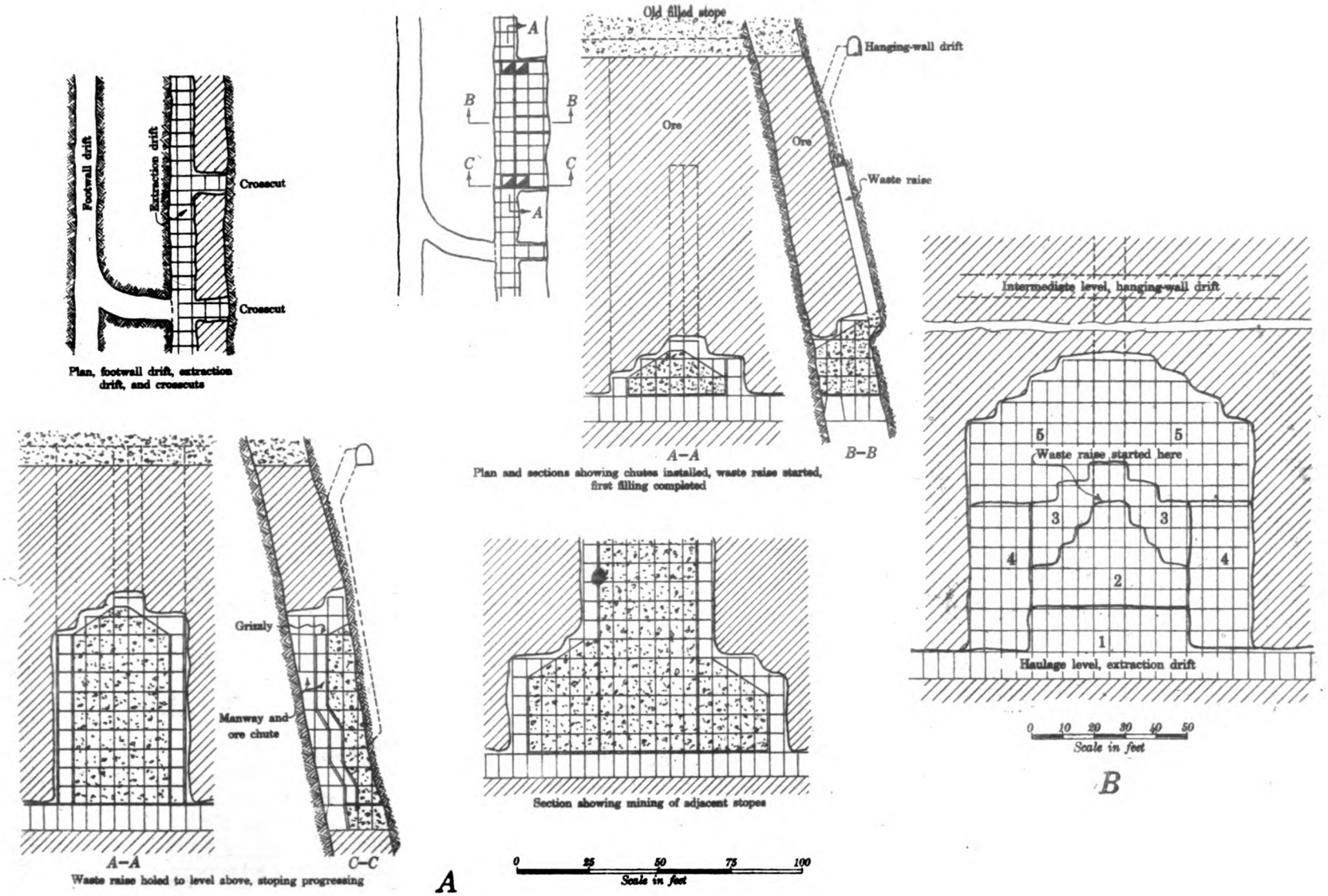

Figure 22.— Rill stoping, Magma mine: *A*, Timbered-rill method; *B*, modified timbered-rill method.

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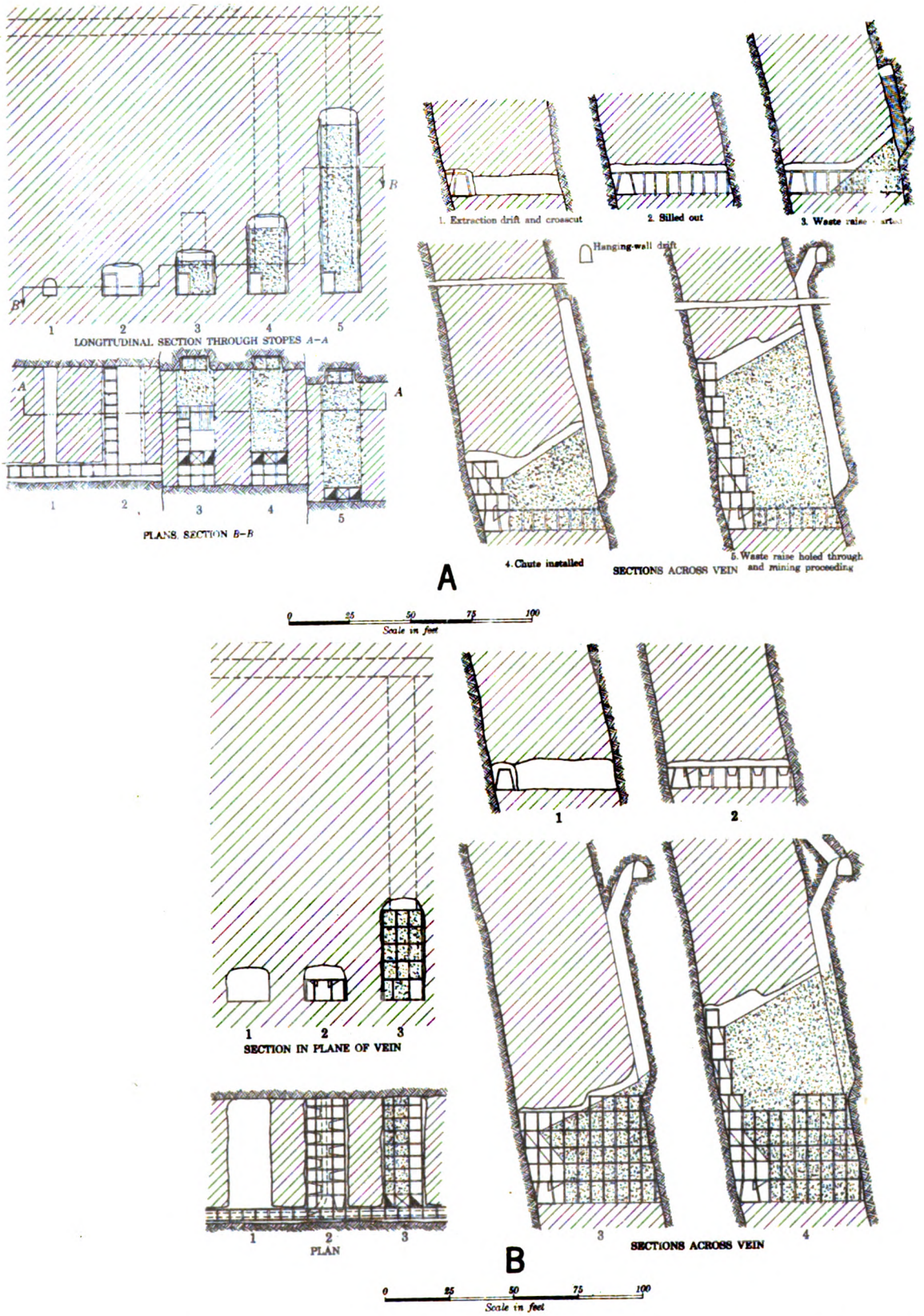

Figure 23.—Rill stoping, Magma mine: A, Rill-and-pillar system; B, modified rill stope, stope-and-pillar method.

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At the Champion mine, Painesdale, Mich., where the sublevel inclined cut-and-fill system has been employed for several years, the ore is mined on sublevels by a series of short, inclined stopes.[52] The miners advance the breast up the slope at an angle of 38° (fig. 2) until only a small pillar 2 to 4 feet thick is left supporting the fill in the worked-out stope above. In wide stopes the pillar is 4 feet thick. After each round is blasted the copper rock is picked out and thrown back, and the waste rock is left as filling. About 40 percent of the rock broken is discarded as waste. The pillar at the top of the stope slice is drilled, and the holes are left standing until all copper rock has been picked out and all exploration has been done on the foot and hanging sides. The pillar is then blasted, and the fill from above rushes down and completely fills the stope. Most of the copper rock in the pillar is found at the bottom of the pile of waste, where it can be picked out.

At the Magma mine, Superior, Ariz., a timbered-rill stoping system is employed where the vein is less than 15 feet wide and a combination rill-stope-and-pillar system where the vein is wider.[53] In the timbered-rill system (fig. 22, A) a 34- to 40-foot stope is started and is inclined from the top of the sill set at each end to 4 or 5 sets high in the center. A two-compartment cribbed waste raise is driven in the hanging wall next the vein from the top floor to the level above. The top of the ore chute is protected by grizzlies; after each filling of the stope a new grizzly is built over the chute. Filling is discontinued before the waste covers the tops of the square-sets so that succeeding cuts can be placed without digging. The angle of repose of the fill is roughly 2 horizontal sets to 1 vertical. After the stope is filled a floor of 2- by 10-inch by 5-foot lagging is laid on the waste. Succeeding stopes are 15 to 25 feet long; the back is sloped away from the fill at an angle corresponding to the angle of repose. The stope is mined to the level above by alternately taking two or three 7-foot cuts and then filling, and waste is run in through the extraction raise of the previous stope. A series of stopes may be worked at one time, and occasionally waste fill may be run from one stope into the next.

Figure 22, B, shows a variation of this method in which the vein is silled for a length of 10 sets and a height of 2 sets above the sill. This space is timbered, and the back is pyramided to a height of about 8 sets in the center, from which point a waste raise is run to the level above. Just enough ore is mined by this first operation so that the waste produced in driving the raise will fill the space. "Wing" stopes are then started at each end, and filling for these is run in over the filling of the center stope. In this way 18 sets or 90 feet along the vein can be filled with only 1 waste raise. When the center of the stope reaches the level above and the fill will no longer run by gravity to the ends of the stope short raises are cut to the level above near the ends.

In the rill stope-and-pillar system the ore is mined by 16-foot rill stopes alternating with 14-foot pillars across the vein (fig. 23, A). The back of the stope is inclined upward to the hanging wall at about 35°, approximating the angle of repose of the filling material. After the ore is cleaned out gob lines consisting of single posts end on end and 2-inch lagging are placed along each side of the stope against the pillar, and a single strand of old hoist cable is used to tie corresponding posts on opposite sides of the fill together. The waste raise advances only fast enough to furnish the required fill and usually reaches the level above when the stope is 35 feet high on the hanging-wall side.

A modified form of this method is shown in figure 23, B. The stope is square-setted to a height of 50 feet at the hanging-wall side, from which point a waste raise is driven to the

52 Mendelsohn, Albert, and Jackson, Charles F., The Sublevel Inclined Cut-and-fill Stoping System: Trans. Am. Inst. Min. and Met. Eng., vol. 102, 1932, pp. 43-58.

53 Snow, Fred W., Mining Methods at the Magma Mine, Superior, Ariz.: Inf. Circ. 6168, Bureau of Mines, 1929, 32 pp.

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level above. The raise can thus be pushed through without interruption and will furnish just enough waste to fill the space already stoped. From this point stoping continues as in the regular system.

The stopes are carried up the full lift between main-haulage levels. Intermediate levels are used for bringing in supplies and filling and as a means of access to the stopes.

Figure 24 shows the method of square-set stoping used at the Park-Utah mine.[54] The length and height of the stope section are determined by the angle of repose of the waste filling, which is about 40°. The enclosed lines in figure 24 represent the angle of repose of the waste fill at various stages of mining. Waste is run in from time to time as the square-set sections are being carried up so that mining and filling are continuous. The waste is derived largely from development work and is run into the stope from hanging-wall raises connecting with the hanging-wall drift on the level above (fig. 24). As the stope advances to the position shown by the dotted lines additional waste raises C-W and C-E are driven. Waste raises are 100 feet apart. Horses of waste occurring in the ore are drilled and blasted into the fill.

At the Ground Hog mine the ore is mined and the stopes filled, using very little timber where the vein is narrow; where the vein is wide, filled square-set stoping is employed.[55] A rill stope is started by stoping next to the center raise of a block to as great a height as possible and then running fill in through the raise to its natural angle of repose. Floor is laid on the fill; a 3-foot inclined cut is taken out, and filling is run in again. This cycle is repeated until the toe of the slope is within about 10 feet of the chute, after which the length of the slide is not increased further and a level space is maintained next to the chute during subsequent operations for a shoveling floor.

Waste sorted from the ore at this point is thrown into the adjoining section on the other side of the chute. In filling a slice as little room as possible is left under the back. The filling spreads almost entirely by gravity. Figure 25 illustrates several stages of stoping, using square-sets and filling. When the stope is completed a vertical line of sets usually is lagged off to serve as a waste pass for transferring waste to lower levels.

In the foregoing examples the stopes have all been carried on an incline so that the filling runs into place by gravity, and very little handwork is required for placing it in position. Where the ore is mined in short, narrow, vertical slices or sections, with a waste pass for each section, little handwork is required in spreading and leveling the fill. At the United Verde Extension mine a fill hole is thus maintained in about every sixth set, several floors are mined before filling, and very little shoveling of waste fill is required.[56] If conditions are such that the waste will not spread, a light, metal, gob chute is placed in the fill hole, and the waste is spread with a car or wheelbarrow.

When the ore is mined in large horizontal slices or floors and filling is introduced from outside the stope, closely following the removal of each slice of ore, hand or mechanical means must be employed for handling and placing most of the fill unless there are a large number of fill holes.

Figure 26 shows the stringer-set-and-fill system of stoping employed at the Hecla mine, Burke, Idaho.[57] In starting a stope a central raise is first driven to the level above.

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54 Hewitt, E. A., Mining Methods and Costs at the Park-Utah Mine, Park City, Utah: Inf. Circ. 6290, Bureau of Mines, 1930, 17 pp.

55 Richard, F. W., Mining Methods and Costs at the Ground Hog Unit, Asarco Mining Co., Vanadium, N. Mex.: Inf. Circ. 6377, Bureau of Mines, 1930, 13 pp.

56 D'Arcy, Richard L., Mining Practice and Methods at the United Verde Extension Mining Co., Jerome, Ariz.: Inf. Circ. 6250, Bureau of Mines, 1930, 11 pp.

57 Foreman, Charles H., Mining Methods and Costs at the Hecla and Star Mines, Burke, Idaho: Inf. Circ. 6232, Bureau of Mines, 1930, 21 pp.

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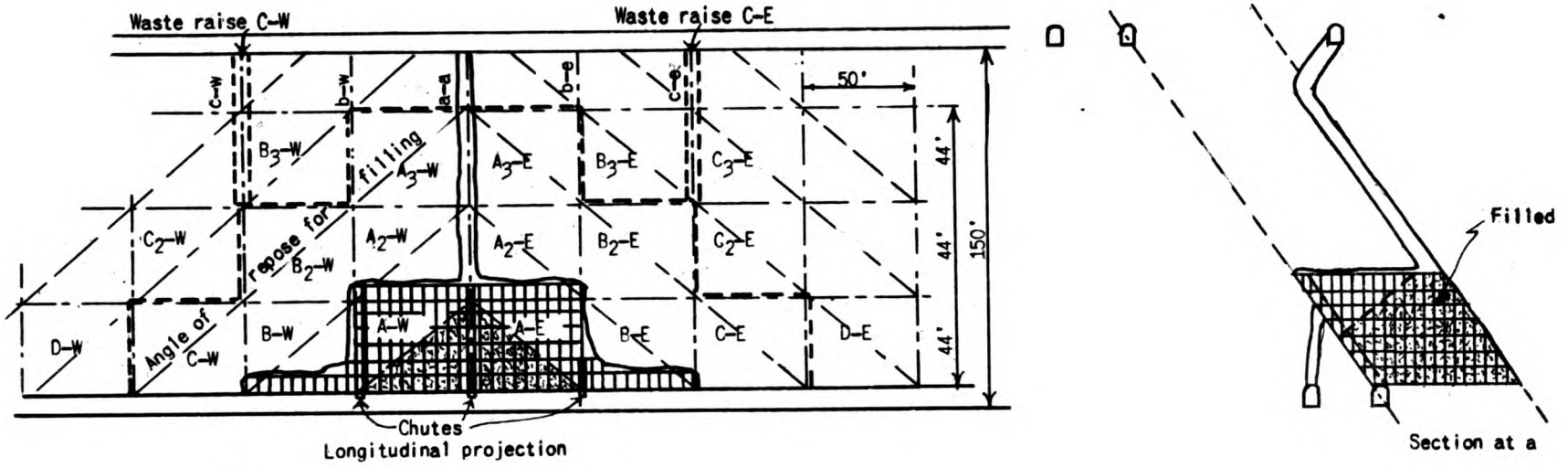

Figure 24.- Square-set method, Park-Utah mine.

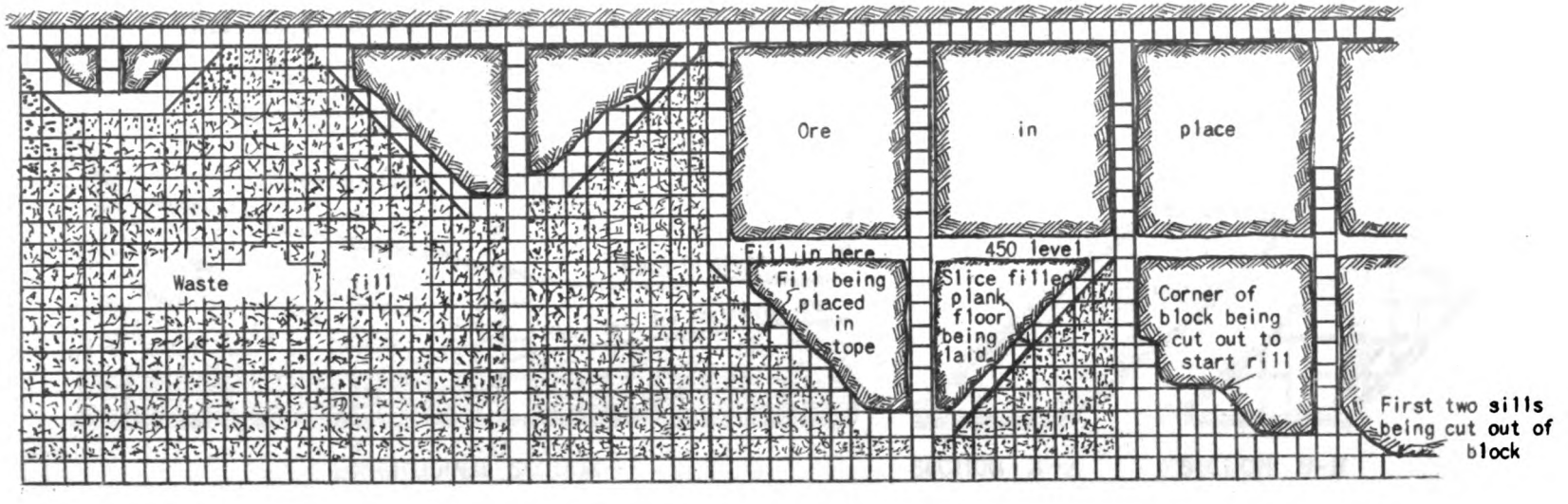

Figure 25.- Square-set stope and filling, Ground Hog mine.

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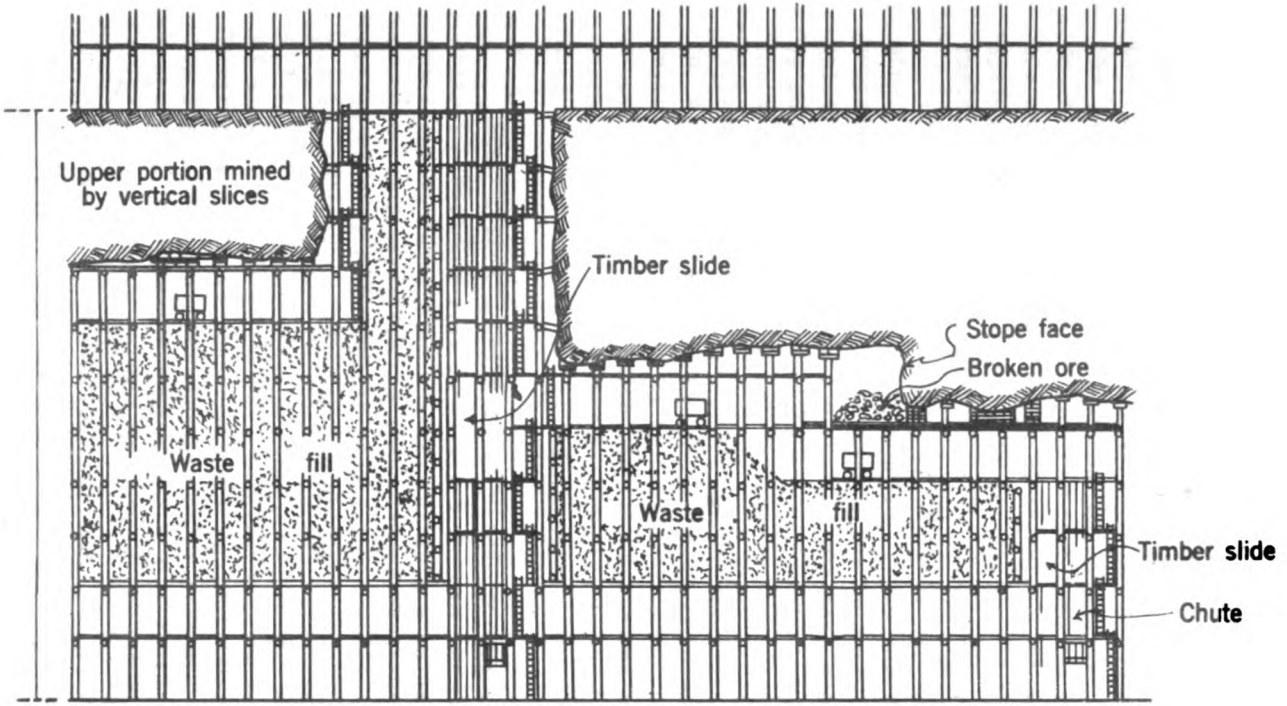

Figure 26.—Generalized section showing stoping-and-filling method, Hecla mine.

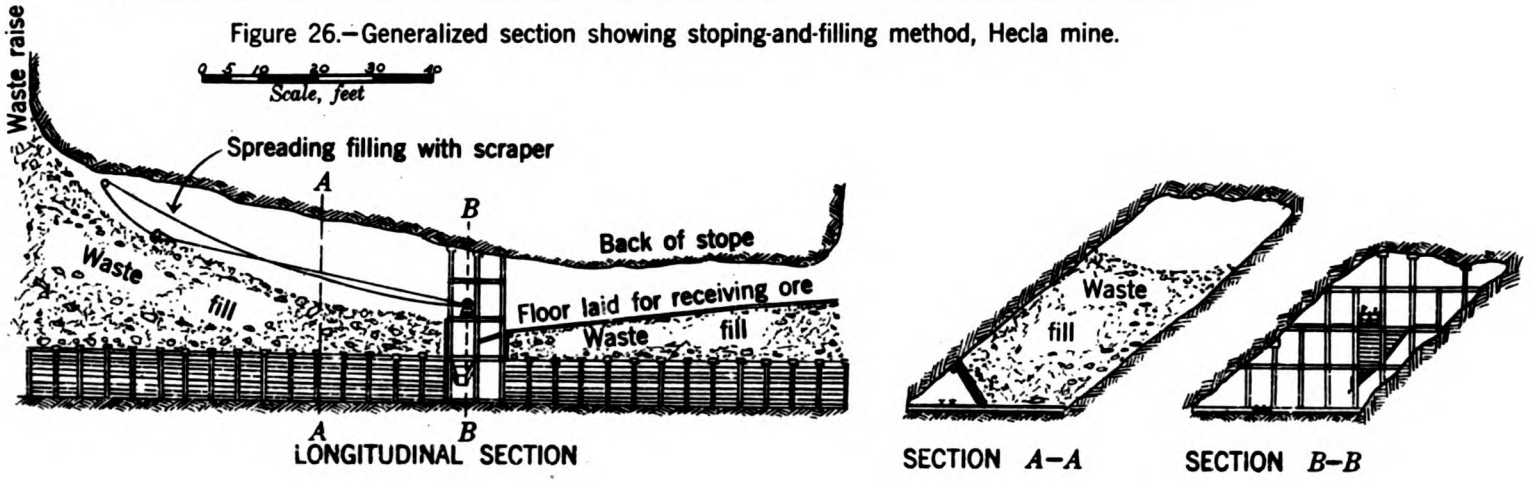

Figure 27.—Scraping fill in flat open stopes, Park-Utah mine.

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After the first three floors have been mined the ore is trammed to the end raises. Waste for filling is drawn from the chute compartment in the central raise. The first floor is mined from the central raise to the end of the block and timbered as the face advances. The ore is passed through the top lagging of the drift sets into cars on the level. The second and third floors are then mined in the same manner. While the third floor is being mined the timbers for supporting the filling in the stope are laid. The bottom of the waste corral is over the first floor above the sill, thus leaving the first floor open to allow repair of the drift timbers and the corral bottom. After the third floor is far enough advanced the second floor can be filled from the raise; a track is laid on the third floor for tramming waste coming from the level above through the central raise. When the third floor is completed and the fourth floor started the track on the third floor is used for transfer of broken ore from the face, the ore being dropped into the car and thence trammed to the chute. When the fourth floor has advanced 25 to 30 feet from the raise filling is started on the third floor, the waste coming from sorting on the mining floor and from the central raise. By using this system virtually one floor only is open at a time. If wall conditions permit, the track for waste filling is laid only on every second floor, and two floors are then filled at a time.

Figure 27 shows the method of spreading filling in flat open stopes at the Park-Utah mine.[58] A cut-and-fill stope may be made any width if walls and ore are hard; the length averages about 100 feet. When a stope is mined by advancing upon broken ore as high as the walls will permit without sloughing the ends are lagged and the ore is dragged to the chute by scrapers. Waste is run in through the end raises and is dragged into place by a scraper. The scraper drags close to the foot wall, and that part of the stope is easily filled. The filling is then completed under the hanging wall, and a blasting floor is laid in preparation for mining the next slice. When the waste consists of fine material the floor is laid directly on the fill; when it is coarse cross-stringers are used under the floor. In very flat stopes or with sticky waste the filling is washed into place with water, forming a compact, loosely cemented filling which is particularly desirable on the sill floor. Wet waste, however, causes trouble, as it runs into the chute and manway if the slope of the floor exceeds 10°.

About a week usually is required to drag in waste filling and level it off with the scraper. When the fill is within 5 feet of the back it is leveled off carefully by hand, and the floor is laid. Two shifts usually are required to level the fill and lay the floor.

At the Tintic Standard mine[59] the general plan of stoping is to drive a vertical square-set raise from the footwall at the level of the stope to the level above. The raise is the place from which the stope is started and through which waste is dumped for filling. For every stope (not section) started at least one waste raise is required. The first section of a stope is started at the raise and is 2 or 3 sets wide; it extends from the raise to the hanging wall and is mined up floor by floor as high as safety will permit and then filled, leaving manways outside the section at convenient places. This section is completed to the hanging wall or mined 8 floors high and is filled before a new section 2 sets wide is started from the sill on one side. While the second section is being filled a third is started on the other side of the original section. By alternating from one side to the other a regular tonnage of ore can be maintained. After a section has been mined and is ready for the filling it is thoroughly cleaned of broken ore, and the floor lagging is taken up and nailed on the inside posts against the solid ore for gob lagging. Filling in stopes will settle as much as 7 feet between levels of 120 feet. The result is great distortion of the timber and settling

58 Hewitt, E. A., Work cited.

59 Wade, James W., Mining Methods and Costs at Tintic Standard Mine, Tintic District, Utah: Inf. Circ. 6360, Bureau of Mines, 1930, 21 pp.

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of the filled stope on the level above, leaving room for movement of the hanging wall. Timbers in the sections mined along the sides of these filled stopes are affected considerably. Shrinkage of the gob can be reduced if wet material is available or if the fill is sprinkled as it is placed to reduce the voids. These remedies cannot be used at this mine, however. Water reaching the ore removes cementing material in the ore and makes it more troublesome to mine. Moreover it would be dangerous to permit water to percolate through old fills and caves.

The best method found to combat settling under the conditions at this mine is to keep the filling as close to mining as possible, allowing the stopes to settle during the mining period. Movement of fill on the level above is thus reduced to the minimum after mining under its sills.

At the Bunker Hill & Sullivan mine[60] square-sets are erected as fast as the ore is removed in the stopes and as soon as convenient they are tightly lagged with slabs and filled with waste.

Stoping is started on the hanging-wall side of the vein. Sills are covered with slabs and square-set timbers placed; these are extended, and the back row is filled to support the wall. A new floor is started above the sill floor, the first row of square-sets extending into the hanging wall to obtain filling for the sill floor; stoping then progresses toward the foot wall. A steeply arched back is maintained at all times. About the center of the ore shoot a raise is started on the foot wall from the foot-wall drift and driven to the level above (fig. 28). It is then timbered to provide a waste pass and a timber pass with a manway between. The foot-wall raise is connected by a row of square-sets with the top floor of the stope when the latter has reached the elevation shown in figure 28, B; track is laid, and waste is drawn from the raise and distributed by hand-trammed cars. The stope is worked so that the highest part is at the raise, thence sloping down to each end.

Horizontal cut-and-fill stoping is used in the lower levels of the Colorada mine at Cananea.[61] The typical stope is 30 feet wide and 50 to 160 feet long and has a row of raises along the center line spaced at 40-foot intervals. These stopes are mined between pillars by regular horizontal cut-and-fill methods. As soon as a stope is large enough, a scraper is installed to move the ore to the chutes, and the stope is advanced laterally by breast stoping. When it has passed the next raise the first part of the stope is cleaned out, a floor of 2- by 10-inch plank is laid, and gob fences are built around the stope, except on the waste sides. Filling is run in though the waste raises and spread by scraper and wheelbarrow to within about 3 feet of the back. Fine waste is used when available for the top foot or two of fill for convenience in laying and leveling the floor. After the stope has been filled a temporary floor is laid on the waste, and a second cut is started.

At the Pilares mine 59.4 percent of the ore mined in 1929 came from horizontal cut-and-fill stopes.[62] Fill raises are driven 30 to 50 feet apart along the longest dimension of the stope (fig. 29). As the stope cuts progress sorted waste is piled to one side. aste filling follows closely behind the cut so that production is virtually continuous. Wherever possible "joker chutes" are placed under the fillholes, and the waste is handled with cement buggies. Where fill holes are poorly spaced hand-trammed cars are used for spreading the fill. Slushers with double-drum air hoists have worked successfully in several large stopes.

60 Brown, U. E., Mining Methods of the Bunker Hill & Sullivan Mining & Concentrating Co., Kellogg, Idaho: Inf. Circ. 6407, Bureau of Mines, 1931, 9 pp.

61 Catron, William, Mining Methods, Practices, and Costs of the Cananea Consolidated Copper Co., Sonora, Mexico: Inf. Circ. 6247, Bureau of Mines, 1930, 41 pp.

62 Leland, Everard, Mining Methods and Costs at the Pilares Mine, Pilares de Nacozari, Sonora, Mexico: Inf. Circ. 6307, Bureau of Mines, 1930, 34 pp.

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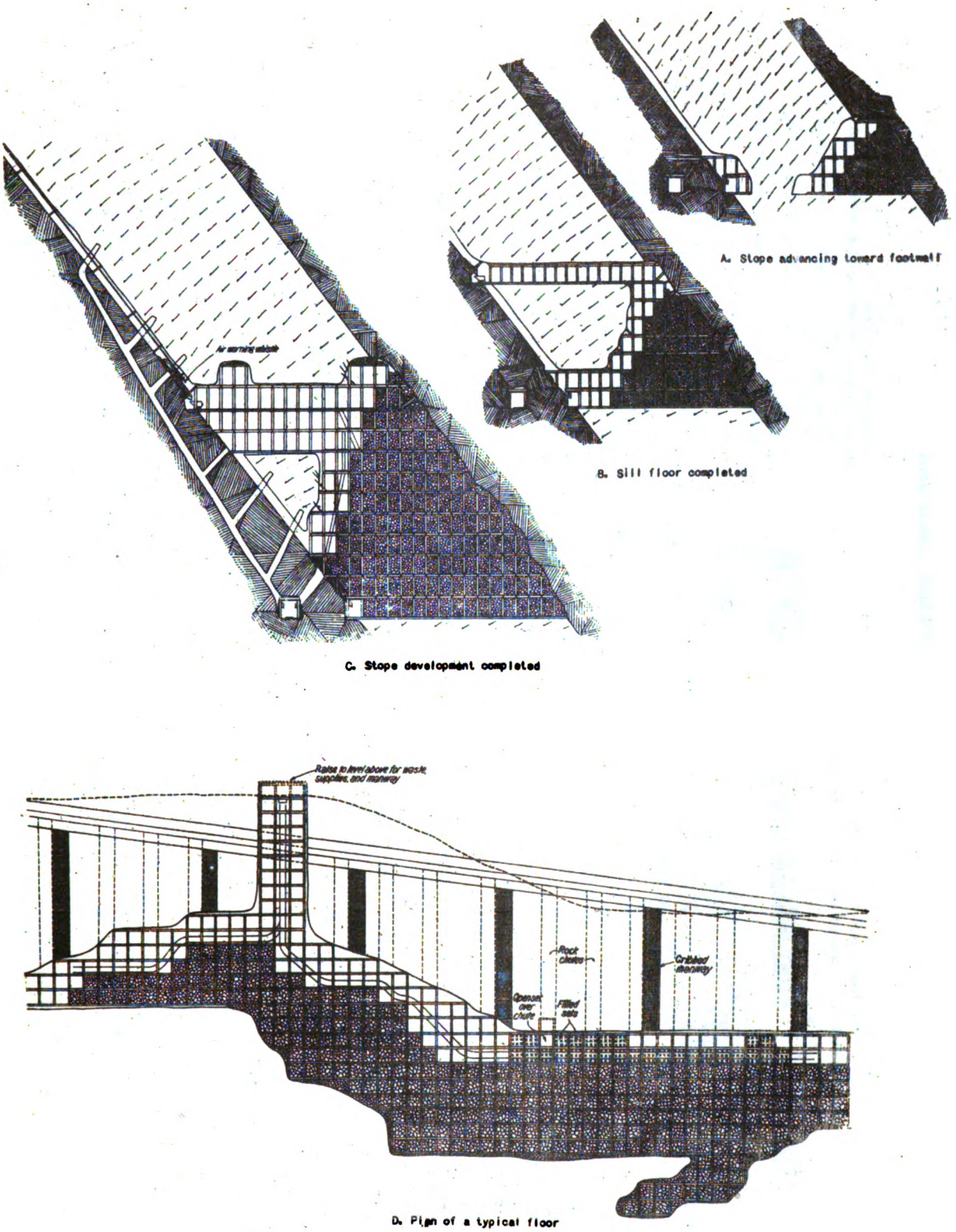
A. Stope advancing toward footwall
B. Sill floor completed
C. Stope development completed
Raise to level above for waste, supplies, and manway
Rock chute
Ore pass or chute
Filled into
Cribbed manway
D. Plan of a typical floor

Figure 28.— Square-set stoping showing method of filling at the Bunker Hill & Sullivan mine.

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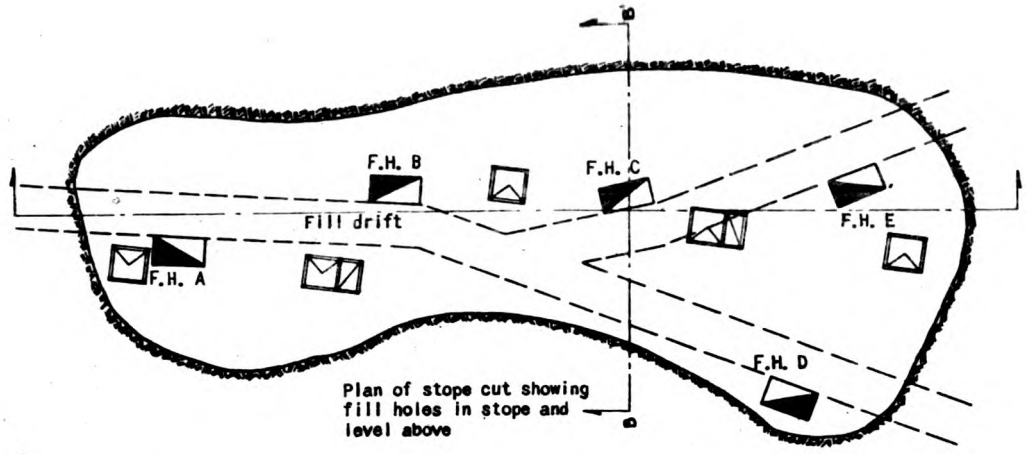
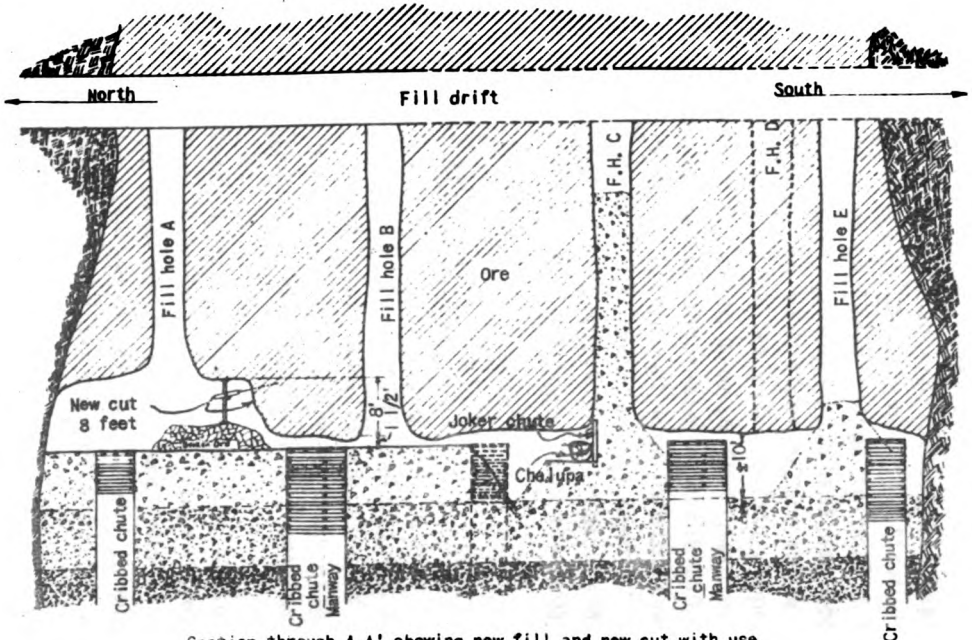
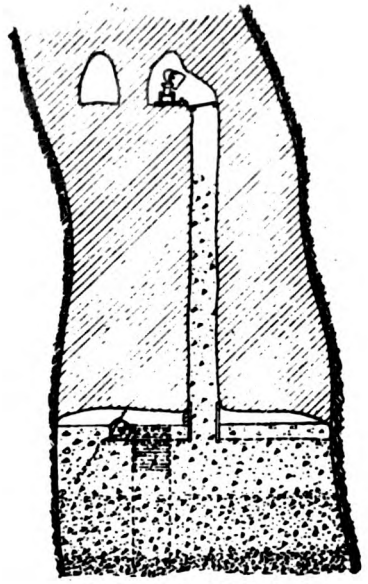


Plan of stope cut showing fill holes in stope and level above



Section through A-A' showing new fill and new cut with use of joker chute and "chalupa."



Section through B-B' showing joker chute and "chalupa" in use

REMARKS

1. As new cut advances, south end of stope is being filled through C, D, and E with cement buggy or "chalupa."
2. Joker chute can be moved around fill hole to most desirable position.
3. Fill holes originally were spaced as nearly as possible on 30-foot level – considered best.
4. When new cut is sufficiently advanced, chutes are raised 8 feet and filling of north end starts.
5. When this cut is finished, north end has been filled and new cut starts over new fill, advancing behind it.

WASTE FILL

1. Reaches stope with all degrees of moisture from very wet to fairly dry.
2. Angle of repose varies from 45° for dry to 60° or even 90° for wet.
3. Component parts of fill vary in diameter from dust to +15 inches.
4. Weight of fill varies from 100 pounds to 150 pounds per cubic foot.

Figure 29.—Typical cut-and-fill stope in operation, Pilares mine.

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Experience has shown that the waste packs well and that by the time mining operations from below reach the fill of mined sections above little difficulty is experienced in mining the ore fairly clean.

At the Block P mine, where sorted waste furnishes all the fill required, rock walls are built of large slabs around the top of the ore passes to a height of 4 feet far enough back from the outside lines of the finished chutes to allow room for standing the next set of chute timbers inside. The rock walls permit the stope floor to be raised to the height of one set without timbering the chute and the ore can be shoveled directly into the chute without throwing it over a 5-foot set of timbers. After the wall is 4 feet high a set of timbers is placed inside and lagged, and the space between the wall and the timber is filled. The top set is thus always protected from blasting.

In 1929, 61 percent of the ore mined at the United Verde mine came from horizontal cut-and-fill stopes.[63] Figure 30 is a section of a typical stope, showing the method of mining and filling. Individual stopes vary greatly in size - they may be 30 to 160 feet across the orebody and 60 to 200 feet along the strike. In the smaller stopes only 1 waste raise is used, but in stopes more than 100 feet long 2 raises insure continuous production and provide better ventilation; the second raise is placed near one end of the stope. Slices are mined 7 feet high; as soon as a slice has been mined and cleaned out past an ore chute the chute is raised 7 feet, and filling is started. Enough waste is first dumped down the waste raise directly into the stope to form a bench large enough to hold a bulkhead waste chute. Filling is then continued by hand-tramming in specially designed scoop cars (fig. 21). Gob fences are built along the pillar lines on each floor before waste is introduced.

At the McIntyre mine, Schumacher, Ontario, horizontal cut-and-fill stopes are employed for mining half or more of the ore.[64] Breasts are mined 8 to 10 feet high, using horizontal holes. Waste is trammed from waste passes spaced at intervals of about 200 feet along the strike of the vein in long stopes; if the waste is introduced from outside the stope through these raises it is trammed from the raises in cars and is spread by hand.

As previously noted, some stopes are filled with waste from crosscuts driven into the walls. In this event the waste is handled in cars or is dragged from the crosscuts by power scrapers and delivered to the place being filled.

Sand and Mill Tailings

Sand and mill tailings are similar with respect to handling and placing in stope fills. If coarse gravel is mixed with the sand the methods of handling and placing are limited to those already discussed - gravity and shoveling by wheelbarrow or cars or power scrapers. Fine material, however, may be handled by hydraulic or compressed-air methods as well as by these more conventional methods.

The method of separating mill sands from the slimes and conveying it to the stopes at the Matahambre mine in Cuba has already been discussed. In the stope itself the sand is directed wherever wanted by pipe or hose; by building up small sand dams it is possible to fill any part of the stope. After 12 hours the water has seeped out through the burlap, which is wrapped around the cribbed ore passes to retain the sands in the stope, and the floor of the stope is almost as hard as ordinary soil.

63 Quayle, T. W., Mining Methods and Practices at the United Verde Copper Mine, Jerome, Ariz.: Inf. Circ. 6440, Bureau of Mines, 1931, 31 pp.

64 Skavlem, H. G., Mining Methods and Costs at the McIntyre Porcupine Mines, Ltd., Schumacher, Ontario: Inf. Circ. 6741, Bureau of Mines, 1933, 18 pp.

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At the Champion mine, Painesdale, Mich., stamp sands were dumped into the stopes through a raise, the bottom of which was stopped off by a sollar to which was attached a 10-inch pipe and gate for drawing the sand from the raise into a tank.[65] The tank was cylindrical and had a capacity of about 1 1/2 tons (fig. 31). It was coned at both ends, and the top cone contained a counterbalanced gate that swung down away from the flow of the sand when the tank was being charged. This gate or valve seated against the underside of the head by means of a rubber gasket, making an airtight compartment when closed. The bottom cone of the tank was connected to a 6-inch tee placed horizontally and connected at one end through a reducer to a 4-inch distributing pipe which rested on the fill. The other end of the tee had a reducing flange to the inside of which was secured a short 1-inch pipe nipple reduced at the end to form a nozzle. A 1 1/4-inch pipe connected the outside of the reducing flange to the top of the tank and in turn was connected to the main air line, valves being suitably placed to permit regulation of air either to the top or bottom of the tank as required. Extra-heavy black pipe cut in 6-foot lengths and joined by Dresser couplings was used in the distributing line. These couplings allow deflection of the pipe around obstructions. A threaded pipe would wear only about half as long, for when it would be half worn, the root of the threads would be exposed and the thread cut off. With Dresser couplings, however, the pipe could be used until worn through. The pipe lasted 3 to 6 months.

The sand was drawn from the raise into the tank, and when the tank was almost full the upper gate was closed and then the counterbalanced valve. Compressed air was admitted, seating and holding the balanced valve, and the pressure in the tank fed the sand through the lower cone into the tee. The air jet from the nozzle cut away the falling sand and carried it to the distributing pipe. When the tank was nearly empty the air was shut off, allowing that confined in the tank to expand and expel the remainder of the charge. By shifting the pipe line the sand filling was carried the full width of the stope; and as the fill advanced, the line was extended. The sand left the pipe with enough force to be carried about 20 feet beyond the end of the pipe. Sand was easily transported 250 feet in this manner. The air pressure was 75 to 80 pounds. Two or three minutes were required to load and discharge a tank of sand (1 1/2 tons), depending upon the length of the line and the fineness and moisture content of the sand. The shorter the line or the coarser or drier the sand (up to 40-mesh) the greater the speed of operation. One man was required to operate the tank and extend the line; 500 to 1,500 cubic feet of free air was used per ton of sand moved, involving a power cost of 2 cents per ton of sand.

A somewhat similar system has been employed by the New Jersey Zinc Co. at Franklin, N.J.

In some of the mines on the East Rand, where the reef is 3 to 6 feet thick and the dip 10 to 15°, neutralized tailings from the cyanide mills have been used to support the hanging wall in stopes.[66] The sand is sent underground through boreholes, which are 6 inches or more in diameter and are drilled with shot drills at a cost of about $4 per foot. In government areas at Brakpan there are 2 holes, one 2,133 feet deep which deviated 353 feet from its course and one 3,235 feet deep which deviated 430 feet. If the sand is taken directly from the mill it is mixed with equal parts of water and is pumped through 12- to 15-inch concrete and steel pipes to the borehole, where it is dewatered by a drag classifier. If it comes from a tailings dump it is flushed to the classifier with a hose. The sand from the classifier falls into a hopper above the borehole, and enough water - 1 part to 2 or even 3 parts of sand - is added to make it flow down the hole. From the bottom of the borehole the sand

65 Schacht, W. H., Mining Methods of The Copper Range Co.: Trans. Am. Inst. Min. and Met. Eng., vol. 72, 1925, pp. 346-370.

66 Eaton, Lucien, Sand Filling Through Pipes and Boreholes: Trans. Am. Inst. Min. and Met. Eng., vol. 102, 1932, pp. 33-42.

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is distributed in launders made of 1-inch boards set at grades of 5 to 30 percent. To completely fill the stope, a barrier consisting of rock and light stulls backed by coco matting is built along the bottom and across any holes through the barrier pillars, and the sand is flushed in from above as rapidly as it will drain. If the dip of the hanging wall is less than the angle of rest of the sand the stope can be filled completely. To make an artificial pillar, a barrier of props backed by wire netting and coco matting is constructed around the limits of the pillar, an opening being left at the highest point. The distributing launder discharges the sand close to the hanging wall at this point, and the pulp flows down over the footwall. The sand packs solidly and provides almost perfect support for the hanging wall. Costs are given as $0.185 per cubic yard of sand. (It seems improbable that the cost of pumping the water back to the surface is included in this figure.)

An article by Henry Dierks on pneumatic stowage in German coal mines was cited by Eaton. (See footnote 66.) Waste from development and washery refuse, ashes, or sand from the surface are trammed to an underground central storage bin. All this material is passed over a screen and the oversize crushed. It is fed by a disk feeder into a pipe line in which a continuous stream of air at 8 pounds pressure per square inch is passing. Close regulation of the feed is necessary to prevent waste of air and clogging of the pipe. In a 10-inch pipe pieces of slate 3 inches in diameter can be blown 1,500 feet horizontally without difficulty. The capacity is usually 30 to 40 cubic yards per hour, and the fill produced is as satisfactory as that deposited with water. The volume of air required is about 300 times the volume of the material transported. About 6 hp. of connected load per cubic yard of hourly capacity are required for compressor, crusher, and feeder.

The use of beach sand for filling at the Hodbarrow mine in Cumberland, England, has already been mentioned.[67] In cut-and-fill stoping a main haulageway is driven in the footwall about 15 feet under the ore, and chutes are built and vertical raises extended into the ore at 60-foot intervals. From these raises crosscuts are driven right and left to the limits of the block to be mined, and the raises are connected by a drift. From the end of each crosscut a drift is driven right and left halfway through the pillar, and when these are completed the crosscut is dammed off with plank. Brattice cloth is hung behind the plank and also along the sides of the drift on which ore is still to be mined. Sand mixed with water is then blown in to fill the opening. Difficulty is experienced in filling the space above the bottom line of the caps of the timbered drifts and crosscuts. When the first drift has been filled another one is driven alongside it and filled in turn. This procedure is repeated until the side of the pillar left to protect the haulageway has been reached. The crosscuts are then filled back to the raises, the raises are extended one slice higher (9 feet), and the next level is sliced out and filled in the same manner as before.

COST OF STOPE FILLING

Data on costs of stope filling are limited; some are in terms of cost per ton or yard of filling and others in terms of cost per ton of ore mined, so that no satisfactory grouping of costs in tabular form can be presented. In a few instances costs per ton of ore mined in terms of man-hours for filling have been given.

At Matahambre, Cuba, the total cost of procuring, handling, and distributing mill-sand filling by the method described is given as 25 cents per ton of sand, as follows:

67 Eaton, Lucien, Work Cited.

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	Cost per ton of sand
Labor..	$0.105
Burlap	.048
Pipe....	.071
Pump....	.006
Power..	.020
Total	.250

Since no pipe had been replaced during the period covered the item $0.071 for pipe is high; the actual total cost probably did not exceed 20 cents.

At the Tintic Standard mine waste was broken in an opencut and delivered to the shaft at a contract price of 20 cents per ton.

In one opencut at Cananea 9 to 10 men delivered 310 tons of waste per day to the chutes at a cost of 13 cents per ton. At another opencut supplying 500 tons per day 34.9 tons of waste per man-shift were supplied to the chutes at a cost of $0.098 per ton; powder consumption was 0.12 pound per ton.

At Cananea the filling cost in square-set, horizontal cut-and-fill, and rill cut-and-fill stopes in the Colorada mine averaged 17 cents per ton of ore produced in August and September 1929.

At the Hollinger mine in Ontario sand and gravel were delivered over an aerial tramway 3 3/4 miles long to waste raises connecting with the surface at a total cost of about 20 cents per cubic yard or about 15 cents per ton.

At the Matahambre mine the cost of filling in 1928 was $0.177 per ton of ore mined, including both rock and sand fill.

At the Pecos mine the labor cost of filling in cut-and-fill stopes in 1929 was 25 cents per ton of ore mined; in square-set stopes, 18 cents; and in underhand pillars, 26 cents. Filling labor amounted to 0.454 man-hour per ton of ore mined.

At the Teziutlan copper mine, Puebla, Mexico, 1.056 man-hours per ton of ore mined were attributable to filling operations, July 1930 to June 1931, inclusive.[68]

At the McIntyre mine in 1930 it cost 50 cents per ton to break waste in stope crosscuts and 30 cents per ton to handle it in cars and spread it by hand. In the large sublevel waste stope previously described, first-breaking cost 10 cents per ton: secondary breaking on grizzlies, loading, and tramming to the main waste pass 25 cents per ton; and stope development, grizzly installation, etc., about 10 cents, a total of about 45 cents per ton of waste.

At another mine sand fill cost 45 cents per ton of sand, including cost of delivery and placing in the stopes and some scaling and timbering in the stopes.

68 Hrivel, Ernest Ph., Mining Methods and Costs at the Teziutlan Copper Mine of the Mexican Corporation, S. A., Teziutlan, Puebla, Mexico: Inf. Circ. 6736, Bureau of Mines, 1933, 15 pp.

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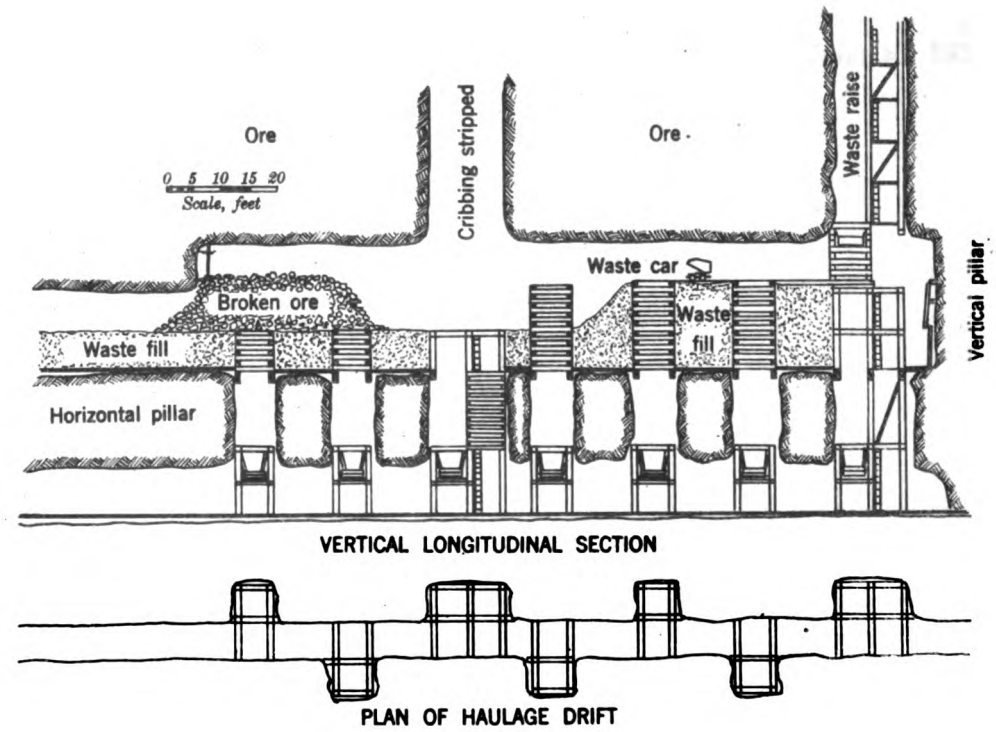

Figure 30.—Typical cut-and-fill stope, United Verde mine.

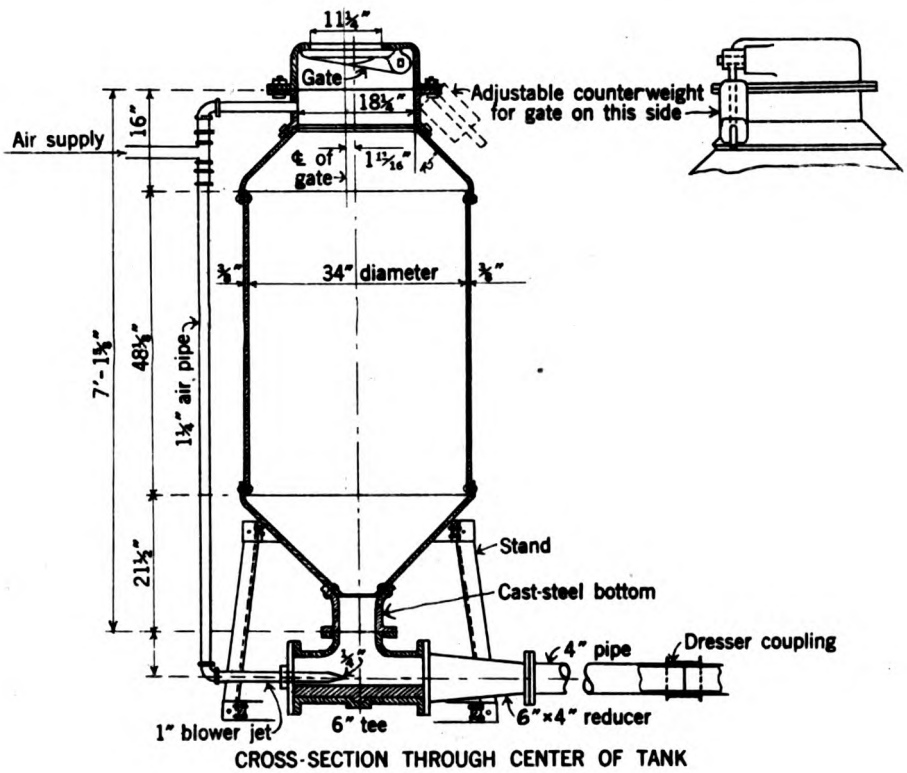

Figure 31.—Sand tank for blowing filling, Champion mine.
(Trans. Am. Inst. Min. and Met. Eng.)

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